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Protein and Energy Supply for High Production of Milk and Meat

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Foreword

The Symposium on Observations on the Practical Use of New Sources of Protein in Relation to Energy Supply for High Production of Milk and Meat was held at the Palais des Nations, Geneva, from 12 to 15 January 1981. The symposium was jointly organized by the Committee on Agricultural Problems of the United Nations Economic Commission for Europe (ECE) and the Food and Agriculture Organization of the United Nations (FAO). Twenty-five participants from twelve countries and from three international organizations attended the symposium which met under the chairmanship of Mr. G. Alderman, Ministry of Agriculture, Fisheries and Food of the United Kingdom. Dr. N.V. Kurilov of the All-Union Research Institute of Animal Physiology, Biochemistry and Nutrition of the USSR served as Vice-Chairman.

The programme for the Symposium, drawn up by the secretariats of the ECE and the FAO, provided for the participants to discuss recent advances in our understanding of the significance of rumen fermentation, recent advances in our understanding of protein/energy relationships in the intermediary metabolism of ruminants as well as the significance of protein/energy relationships in the practical feeding of dairy and fattening cattle.

These proceedings consist of the report of the symposium, nine main reports and one additional paper. The full text of papers presented in the Russian language may be obtained from: The Secretariat, United Nations Economic Commission for Europe, Palais des Nations, CH-1211, Geneva 10, Switzerland.

The Symposium was the third to be called at the request of the ECE Committee on Agricultural Problems and to be organized by the secretariats of the ECE and the FAO on the subject of amino acids. The earlier meetings, the Symposium on New Developments in the Provision of Amino Acids in the Diets of Pigs and Poultry, was held in Geneva from 18 to 22 December 1972, and the symposium on Recent Developments in the Use of New Sources of Protein, Essential Amino Acids and Non-protein Nitrogen with Special Reference to Ruminants from 10 to 13 January 1977 also in Geneva.

Introduction

The Symposium, held in the Palais des Nations, Geneva, from 12 to 15 January 1981, was attended by about 25 experts from the following countries: Austria; Denmark; Finland; France; Germany, Federal Republic of; Netherlands; Spain; Switzerland; United Kingdom, and the Union of Soviet Socialist Republics. Israel and Tunisia were represented under article 11 of the Terms of Reference of the Economic Commission for Europe.

A representative of the following specialized agency attended: United Nations Industrial Development Organization (UNIDO). The following non-governmental organization was represented: European Confederation of Agriculture (CEA). At the invitation of the secretariat, a representative of the Secretariat of the Organisation for Economic Co-operation and Development (OECD) also participated in the meeting.

The deputy director of the FAO/ECE Agriculture and Timber Division opened the meeting.

ELECTION OF OFFICERS

Mr. G. Alderman (United Kingdom) was elected Chairman and Prof. Dr. N.V. Kurilov (USSR) was elected Vice-Chairman of the Symposium.

THE PROGRAMME

The programme of the Symposium was composed as follows :

I. Recent advances in our understanding of the significance of rumen fermentation

(Rapporteurs: Prof. Dr. N.V. Kurilov, Dr. N.A. Sevastyanova (Mrs.) and Dr. V.N. Korshunov of the All-Union Research Institute of Animal Physiology, Biochemistry and Nutrition, Borovsk, USSR, together with Dr. V.V. Tsyupko, Research Institute of Animal Husbandry in the Forest-Steppe of the Ukrainian SSR, Kharkov; Dr. S. Tamminga, Research Institute of Cattle Feeding, Lelystad, Netherlands).

II. Recent advances in our understanding of protein/energy relationships in the intermediary metabolism of ruminants

(Rapporteurs: Dr. J.D. Oldham, National Institute for Research in Dairying, Reading, together with Mr. G. Alderman, Ministry of Agriculture, Fisheries and Food, London, United Kingdom).

III. The significance of protein/energy relationships in the practical feeding of dairy cattle

(Rapporteurs: Dr. M. Journet, Director of the Milk Production Laboratory of the Centre of Zootechnical and Veterinary Research, Theix, Beaumont, France; Dr. I. Kolar, Research Institute for Cattle Breeding, Rapotin, Czechoslovakia; Drs. I. Bruckental, S. Amir and A. Halevi of the Volcani Centre, Beth Dagan, Israel; Dr. L. Syrjälä (Mrs.), Department of Animal Husbandry, University of Helsinki, Finland and Professor Dr. W. Kaufmann, Institute of Physiology and Biochemistry of Nutrition, Federal Dairy Research Centre, Kiel, Federal Republic of Germany).

IV. The significance of protein/energy relationships in the practical feeding of beef (fattening) cattle

(Rapporteur: Professor Dr. K. Rohr, Dr. R. Daenicke and Professor H.G. Oslege, Institute of Animal Nutrition, Brunswick, Federal Republic of Germany).

In addition to these, the following papers were given or made available to participants.

- (i) Presentation of research results on protein/energy relationships in the feeding of dairy and beef cattle in Denmark (Dr. P.D. Møller, Head of the Section of Applied Physiology and Feed Evaluation, National Institute of Animal Science, Copenhagen, Denmark).
- (ii) Studies on the utilization of non-protein nitrogen in the feeding of sheep in Bulgaria (Academician N. Platikanov, Institute of Cattle Breeding, Kostinbrod, Bulgaria).

RUMEN FERMENTATION ASPECTS

The ruminant animal has a remarkable capacity under a wide range of feeding regimes, to convert a wide variety of products which are less suitable for human consumption into high quality human foods. A major determinant of this capacity is the process of microbial fermentation in its forestomach, which ensures a continuous supply of protein and energy to the host animal.

It was stressed that protein and energy metabolism in this fermentation process are highly interrelated. The protein supply of the host animal depends to a large extent on an adequate energy supply to the microbes in its forestomach. The maximization of the energy supply to the host animal also depends on the protein supply of the microbes. Ration type and feeding system influence the effects of protein intake on the energy status of dairy cows. Intake of high forage rations, and particularly those based on maize silage, is more likely to be increased by protein supplements than is intake of high concentrate rations.

It was shown that in most European countries the genetic capacity of the host animal to produce milk or meat sometimes exceeds the capacity of the microbes to provide the host animal with enough nutrients in a sufficiently balanced ratio.

Methods of manipulating microbial fermentation were put forward by which the productivity limits of the host animal can be raised. It was concluded that processing (by heat, formaldehyde treatment, etc.) of protein sources as well as processing of energy sources is efficient in enhancing the efficient utilization of nutrients.

METABOLIC ASPECTS

Intermediary metabolism was defined as the processes governing conversion of absorbed nutrients into products. Variation in the net efficiency of these processes was shown to have a big influence on the calculation of supplemented protein needs for high levels of production. The effects of diet and of physiological state on net efficiency have yet to be established.

To achieve high levels of production, energy and protein metabolism are closely integrated, under endocrine control. Future description of the major control systems might indicate the most appropriate means to manipulate metabolite utilization to advantage.

Energy deficiency also leads to a lack in protein and simultaneously to an excess of ammonia. This excess affects liver functions, possibly leading to metabolic disorders, including fertility problems.

Protein supplements may increase fat mobilization in cows with low energy intake early in lactation. Conversely, it may reduce the fat mobilization in animals fed ad libitum.

NEW SOURCES OF PROTEIN FOR RUMINANTS

The introduction of new systems for calculating the protein requirements of ruminants, has focused interest upon the degradability of protein feeds by the rumen bacteria. Responses to protein of a low degradability may be expected for young fast-growing ruminants and dairy cows in early lactation with yields in excess of 30 kg/per day (equivalent to 6,000 kg per annum). Protein sources of low degradability have a limited role to play in beef cattle diets. Results of feeding trials for beef cattle reported were not in close agreement with predicted protein levels from the new requirements systems. Non-protein nitrogen sources and proteins of high degradability are suitable for beef cattle above 200-300 kg live weight. The supply with protected amino acids (methionine) may produce positive effects on production. It has yet to be established whether there is an additional influence on metabolic pathways.

The protein feeds in use in Europe appear to have the following characteristics:

Soya has a high degradability in the rumen. Correct treatment with formaldehyde can reduce this significantly and benefits are being found in terms of milk yield and fertility of dairy cows.

Rape-seed production and utilization has increased considerably and may continue to do so. It can also be formaldehyde treated with advantage as experiments have shown. Such treatment of rape-seed and soya may be helpful to save protein and may lead to a better utilization.

Fishmeal is characterized by a lower degradability than soya or rape and the processing can be adjusted to enhance this. Despite its cost, some responses to fishmeal supplementation of diets for dairy cattle, calves and early weaning lambs are being obtained but the mechanism of this response require careful study.

Single-cell proteins have not been studied extensively for ruminant diets on account of cost and their high degradability in the rumen.

Forage protein production is declining in western Europe owing to high fuel costs, but the process does produce protein with moderate degradability characteristics, suitable for young calves and dairy cows. The value of forage proteins can be changed by processing and preservation techniques other than heat treatment. Ammonia treatment of fresh forage and formaldehyde treatment of grass silages may have particular benefits although difficult problems with formaldehyde application have yet to be overcome.

Urea utilization in ruminant diets is predicted for certain situations by the new protein requirement systems. Basal diets of maize silage or with low forage proportions and high amounts of cereals seem suitable, particularly for beef cattle over 300 kg live weight. Urea as a supplement to grass silage diets is contra-indicated. Slow release forms of urea (urea phosphate, urea formaldehyde, biuret) may prove to have a wider role than urea.

Industrial by-products such as brewers grains and maize gluten as protein feeds for ruminants were not discussed in detail.

It will be important to establish the effects of using different protein sources and treatment on the quality of products (milk and meat), both for milk and meat technology and for direct consumption.

Suggestions for future symposia

Participants also agreed on the following suggestions for possible items which could be discussed at future symposia:

- (i) Developments in the use of new and non-conventional feeds in ruminant nutrition.
- (ii) Production systems facilitating the use of marginal natural grass land for livestock production.
- (iii) Optimizing animal production from high-roughage rations.
- (iv) Developments in the use of additives influencing rumen fermentation and intermediate metabolism (hormones, vitamins, protected proteins, etc.).
- (v) The influence of nutrition on the quality of meat produced from non-ruminant animals.

Recent Advances in the Study of Substance Conversion in the Stomachs of Ruminants

N. V. Kurilov, V. V. Tsupko, N. A. Sevastiyanova and
V. N. Korshunov

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Nutrition, Borovsk, USSR*

Recent advances in methods of investigation of digestion processes in ruminants allowed to obtain important data on the ways of conversion and utilization of nutrients by animal organism. Data on microbial protein biosynthesis in the stomachs were obtained and conditions promoting a more effective assimilation of ammonia nitrogen by microorganisms were found. The role of easily available energy sources in feed nitrogen utilization and microbial protein biosynthesis could be shown. A conversion of plant into microbial protein was found to be largely conditioned by the level and character of carbohydrates in the ration. When feeding sheep mainly on a hay-concentrate ration, about 20 to 60 g microbial protein passed from the stomachs into the abomasum per day, that was 21-39% of the total chyme protein, and with the use of newly-cut clover with timothy about 62 to 83 g bacteria and protozoa protein, or 40-50% of the total protein intake, passed from the stomachs into the abomasum. Additional inclusion of starch feeds into the ration raised the intake of microbial mass in the abomasum, especially on account of the protozoa. A more favourable effect on bacterial synthesis was produced by a simultaneous administration of sucrose and starch into the rumen.

A value of endogenous nitrogen intake in the rumen in relation to the level and source of protein in the ration was measured. An increase in the portion of non-protein nitrogen in the ration is demonstrated to increase the quantity of endogenous protein secreted into the lumen.

Bacterial synthesis in the rumen of cattle meets the amino acid requirement of cows yielding 12-15 kg milk and of young cattle for a moderate growth. In the case of a high milk performance of cows and of intensive growth of young cattle there arises a need for some amino acids, first of all of methionine. A decrease in the deficiency of limiting amino acids can be reached by additional inclusion of these amino acids into the ration, as well as by high-quality protein additions. Research into the processes of biosynthesis and the degree of feed protein digestion in the stomachs allowed to find out that rumen bacteria could to a great degree utilize simple forms of nitrogenous substances, and that an organism meets its requirements in nitrogen and amino acids from microbial protein synthesised in the rumen and non-degraded feed protein.

The level of microbial protein synthesis and utilization efficiency of feed nitrogen mostly depends on the solubility of feed protein. The increase in the solubility of feed protein is followed by an increase in microbial protein synthesis and at the same time there is a little decrease in nitrogen assimilation owing to losses with urea and nucleic acids of microbial cells. In experiments on sheep with anastomosis between the omasum and abomasum it is found that with the inclusion of urea of high-soluble sunflower cake into ration about 50% feed nitrogen was used for microbial protein synthesis, while when feeding a soybean cake - a low-soluble protein - it was about 35%. With it, a quantity of microbial nitrogen entering the abomasum under feeding urea and sunflower cake was in the range

of 4% of total chyme nitrogen, and with the use of soybean cake - it was not more than 30%. Thus, considerable quantities of easy-soluble nitrogenous compounds are used in the rumen, while greater quantities of low-soluble proteins pass into lower compartments of the digestive tract where they are digested. Nitrogen utilization efficiency of easy-soluble nitrogenous substances decreases for account of great losses of nitrogen with urea and microbial nucleic acids. In order to increase nitrogen and amino acid utilization efficiency a protection of high-quality feed protein against rumen degradation can be used. In experiments on sheep there is shown a possibility of using formaldehyde and propionic acid as a means of protein protection. There are the results of the experiments performed. An expediency of further investigations in establishing levels of protected feeds in rations for lactating cows and young cattle is being discussed. A question is put forward on the necessity of further research on the quantitative value of various feed protein degradation in the rumen, effect of protein solubility on the utilization efficiency of non-protein nitrogenous substances as well as a development of methods for obtaining more significant information on the quantity of microbial protein intake in the intestines, non-degraded feed protein and endogenous nitrogen.

Table 1: INCORPORATION OF ^{15}N INTO RUMEN MICROBES IN SHEEP
(atomic excess per cent)

Fraction	Sampling time	
	3 hrs after feeding	24 hrs after feeding
Bacterial N	1.935	1.321
Protozoal N	0.699	4.271

Table 2: INTAKE OF MICROBIAL NITROGEN AND AMINO ACIDS IN THE ABOMASUM OF SHEEP FED DIET WITH DL-METHIONINE

Diet	TN*		Microbial N		TAA**		Total bacterial and protozoal amino acids	
	g/d		g/d	per cent of TN	g/d		g/d	per cent of TAA
Hay + concentrates	20.3		5.2	25.6	50.5		20.6	40.7
Hay + concentrates + + DL-methionine	20.1		6.7	33.3	53.3		28.8	54.1

*Total Nitrogen
**Total Amino Acids

Table 3: UTILIZATION OF AMINOACIDS IN THE SHEEP INTESTINE

	Output in the abomasum		Excreted in feces		Intestine absorption		Total utilization*	
	g	g	g	g	g	%	g	%
Lys	1.87	2.77	0.90	1.87	67.51		0.97	51.87
His	0.91	0.95	0.24	0.71	74.73		0.67	73.62
Arg	2.01	2.61	0.51	2.10	80.46		1.50	74.62
Asp	2.65	4.68	1.03	3.65	78.00		1.62	61.13
Thr	1.52	2.17	0.44	1.73	79.72		1.08	71.05
Ser	2.06	2.77	0.46	2.31	83.39		1.60	77.66
Glu	4.00	6.00	1.22	4.78	79.66		2.78	69.50
Pro	3.01	2.58	0.51	2.07	80.23		2.50	83.23
Gly	1.74	2.65	0.63	2.02	76.22		1.11	63.79
Ala	1.50	2.19	0.57	1.62	73.97		0.93	62.00
Cys	0.90	1.19	0.15	1.04	87.39		0.75	83.33
Val	2.63	2.59	0.48	2.11	81.47		2.15	81.74
Met	0.56	1.05	0.08	0.97	92.38		0.48	85.71
Ile	2.36	2.92	0.50	2.42	82.87		1.86	78.81
Leu	3.94	4.47	0.89	3.58	80.09		3.05	77.41
Tyr	1.10	1.38	0.35	1.03	74.63		0.75	68.18
Phe	2.42	2.71	0.64	2.07	76.38		1.78	73.55
Total	38.19	54.68	9.60	36.08	78.98		25.58	72.71

*Feed minus feces

Table 4: ABSORPTION OF AMINO ACID IN BLOOD OF SHEEP FED 300 g CONCENTRATES

	before				hours after feeding				Substance Conversion in the Stomachs of Ruminants			
	feeding		1 hr		3 hr		5 hr		7 hr			
	A-V*	absorbed**	A-V	absorbed	A-V	absorbed	A-V	absorbed	A-V	absorbed	A-V	absorbed
Lys	0.10	106.8	0.11	214.5	0.13	249.6	0.09	98.3	0.08	78.2		
His	0.06	64.1	0.05	97.5	0.07	134.4	0.05	54.6	0.04	39.1		
Arg	0.11	117.5	0.12	234.0	0.14	268.8	0.10	109.2	0.11	107.6		
Asp	0.13	138.8	0.14	273.0	0.17	326.4	0.12	131.0	0.13	127.1		
Thr	0.07	74.7	0.06	117.0	0.09	172.8	0.07	76.4	0.06	58.7		
Ser	0.08	85.4	0.08	156.0	0.11	211.2	0.07	76.4	0.07	68.5		
Glu	0.20	213.6	0.22	129.0	0.24	460.8	0.22	240.2	0.21	205.4		
Pro	0.09	96.1	0.10	195.0	0.12	230.4	0.07	76.4	0.08	78.2		
Gly	0.10	106.8	0.12	234.1	0.13	249.6	0.09	98.3	0.10	97.8		
Ala	0.09	96.1	0.10	195.0	0.12	230.4	0.09	98.3	0.10	97.8		
Val	0.10	106.1	0.12	234.0	0.14	268.8	0.11	120.1	0.12	117.4		
Met	0.03	32.0	0.03	58.5	0.04	76.8	0.03	32.8	0.03	29.3		
Ile	0.14	149.5	0.13	253.5	0.15	288.0	0.12	131.0	0.10	97.8		
Leu	0.16	170.9	0.15	292.5	0.18	345.6	0.15	163.8	0.14	136.9		
Tyr	0.07	74.8	0.08	156.0	0.09	172.8	0.07	76.4	0.06	58.7		
Phe	0.08	85.4	0.08	156.0	0.1.	182.0	0.08	87.4	0.07	68.4		

* Arterio-Venous difference, mg%

** mg/h

Table 5: OUTPUT OF ENDOGENIC AMINO ACIDS INTO THE SHEEP
ABOMASUM (per cent composition)

	1st period [*]	2nd period ^{**}	3rd period ^{***}
Lys	6.0	5.9	3.6
His	4.7	5.4	3.3
Arg	6.7	5.1	1.0
Asp	17.0	14.3	12.7
Thr	3.9	3.7	6.9
Ser	4.3	6.2	5.9
Glu	17.8	14.8	18.7
Pro	5.2	3.2	5.7
Gly	5.8	9.8	5.3
Ala	3.4	7.9	8.7
Val	4.8	4.0	3.4
Met	1.7	2.0	2.3
Ile	5.3	3.7	5.3
Leu	5.7	3.1	10.0
Tyr	5.0	8.4	4.7
Phe	2.7	2.4	1.6

* semipurified diet. All nitrogen fed
as urea

** semipurified diet. All nitrogen fed
as amidophosphate

*** semipurified diet without nitrogen.

Table 6: MICROBIAL PROTEIN SYNTHESIS IN THE RUMEN OF SHEEP
FED DIETS WITH UREA, SOYBEAN OIL MEAL OR SUNFLOWER
MEAL

	Urea (1st period)	Soybean oil meal (2nd period)	Sunflower meal (3rd period)
N, intake (g/d)	31.66±0.22	31.76±0.15	31.81±0.23
Total N in the abomasum (g/d)	35.77±0.56	34.33±1.11	34.11±0.53
Protozoal N in the abomasum (g/d)	4.83±0.21	3.68±0.16	5.73±0.10
Microbial N in the abomasum: g/d	11.43±0.17	7.31±0.20	10.32±0.50
per cent of intake	51.36	34.39	50.47
per cent of the total N leaving the rumen	45.45	31.82	47.08
Microbial protein (g/100 g DDM*)	14.97	10.49	14.41

* Digestible Dry Matter

Table 7: EXCRETION OF NITROGEN IN URINE FRACTIONS IN SHEEP
FED DIETS WITH UREA, SOYBEAN OIL MEAL OR SUNFLOWER
MEAL

	1st period*	2nd period**	3rd period***
Total urinous N, g/d	14.38±0.35	12.08±0.28	12.36±0.38
Urea N, g/d	11.56±0.32	8.31±0.20	9.72±0.23
Allantoin N, g/d	0.60±0.01	0.42±0.01	0.59±0.01

Table 8: NUCLEIC ACID NITROGEN IN ABOMASAL CONTENTS IN SHEEP FED DIETS WITH UREA (U), SOYBEAN OIL MEAL (SOM) OR SUNFLOWER MEAL (SM), mg/d

	1st period U	2nd period SOM	3rd period SM
RNA, N	1815.3±57.3	1246.0±21.0	1712.2±85.6
DNA, N	902.5±30.4	548.4±22.4	763.1±18.2
DNA + RNA, N	2717.8±87.7	1794.3±32.0	2475.3±103.7

Table 9: CONCENTRATION OF NH_3 IN RUMEN LIQUID AND IN CHYME ENTERING THE ABOMASUM IN SHEEP FED SOYBEAN OIL MEAL (SOM), mg%

Periods of the trial	Rumen liquid	Chyme entering the abomasum
1st period: untreated SOM	30.46±0.77	11.22±0.17
2nd period: SOM treated with formaldehyde	20.55±0.46	8.32±0.09
3rd period: SOM treated with propionic acid	23.97±1.29	10.5±0.11

Table 10: BALANCE OF NITROGEN IN SHEEP FED TREATED SOYBEAN OIL MEAL (SOM)

	1st period*	2nd period**	3rd period***
Intake, g N/d	20.66±0.76	18.12±0.84	20.33±0.73
Entering the abomasum, g N/d	21.17±0.25	18.31±0.84	21.09±0.41
Excreted in feces, g N/d	6.25±0.14	6.30±0.15	7.11±0.18
Excreted in urine, g N/d	8.58±0.15	5.33±0.15	6.63±0.18
Total excretion, g N/d	14.83±0.14	11.63±0.16	13.74±0.18
Utilization of N: per cent of intake	28.23	35.81	32.42
per cent of entering the abomasum	29.95	36.48	34.38

* untreated SOM

** SOM treated with formaldehyde

*** SOM treated with propionic acid

Table 11: ABSORPTION OF NH_3 IN BLOOD OF SHEEP FED DIETS WITH TREATED OR UNTREATED SOIBEAN OIL MEAL

Sampling time	1st PERIOD*		2nd PERIOD***		3rd PERIOD****	
	A - V**	absorbed NH_3 (mg/min)	A - V	absorbed NH_3 (mg/min)	A - V	absorbed NH_3 (mg/min)
Before feeding	0.51 $\pm$ 0.03	1.04 $\pm$ 0.08	0.36 $\pm$ 0.02	0.67 $\pm$ 0.05	0.52 $\pm$ 0.04	1.06 $\pm$ 0.09
After feeding:						
1 hr	0.62 $\pm$ 0.02	1.67 $\pm$ 0.11	0.52 $\pm$ 0.02	1.40 $\pm$ 0.09	0.65 $\pm$ 0.05	1.76 $\pm$ 0.13
2 hr	0.73 $\pm$ 0.04	2.38 $\pm$ 0.15	0.64 $\pm$ 0.03	2.13 $\pm$ 0.10	0.69 $\pm$ 0.07	2.72 $\pm$ 0.14
3 hr	0.85 $\pm$ 0.04	3.00 $\pm$ 0.09	0.60 $\pm$ 0.03	2.11 $\pm$ 0.11	0.66 $\pm$ 0.04	2.33 $\pm$ 0.11
4 hr	0.83 $\pm$ 0.08	2.76 $\pm$ 0.10	0.44 $\pm$ 0.04	1.47 $\pm$ 0.12	0.63 $\pm$ 0.06	2.10 $\pm$ 0.13
5 hr	0.81 $\pm$ 0.07	2.33 $\pm$ 0.13	0.48 $\pm$ 0.04	1.38 $\pm$ 0.08	0.57 $\pm$ 0.03	1.64 $\pm$ 0.14
6 hr	0.76 $\pm$ 0.06	2.04 $\pm$ 0.08	0.47 $\pm$ 0.03	1.26 $\pm$ 0.10	0.51 $\pm$ 0.06	1.37 $\pm$ 0.11
7 hr	0.79 $\pm$ 0.07	1.93 $\pm$ 0.17	0.51 $\pm$ 0.04	1.24 $\pm$ 0.12	0.44 $\pm$ 0.04	1.07 $\pm$ 0.10
8 hr	0.75 $\pm$ 0.06	1.70 $\pm$ 0.09	0.45 $\pm$ 0.03	1.02 $\pm$ 0.09	0.50 $\pm$ 0.03	1.14 $\pm$ 0.06
9 hr	0.60 $\pm$ 0.04	1.18 $\pm$ 0.11	0.33 $\pm$ 0.02	0.65 $\pm$ 0.03	0.54 $\pm$ 0.04	1.06 $\pm$ 0.13
10 hr	0.55 $\pm$ 0.03	1.01 $\pm$ 0.09	0.35 $\pm$ 0.04	0.64 $\pm$ 0.05	0.54 $\pm$ 0.05	0.99 $\pm$ 0.10
11 hr	0.67 $\pm$ 0.05	1.45 $\pm$ 0.08	0.45 $\pm$ 0.02	0.98 $\pm$ 0.07	0.59 $\pm$ 0.03	1.28 $\pm$ 0.11
Total absorption for 12 hr (g)		1.38 $\pm$ 0.17		0.89 $\pm$ 0.09		1.11 $\pm$ 0.10

* *** **** Semipurified diet. See footnotes to Table 5.

** Arterio-Venous difference, mg%

Table 12: ABSORPTION OF AMINO ACIDS IN BLOOD OF SHEEP FED
SOYBEAN OIL MEAL (SOM)

	1st period* g/h	2nd period* g/h	3rd period* g/h
Before feeding	1.96±0.07	2.17±0.08	2.06±0.07
After feeding:			
1 hr	2.82±0.06	2.88±0.04	2.62±0.07
3 hr	4.09±0.09	4.22±0.09	3.96±0.06
5 hr	2.96±0.06	3.14±0.07	3.12±0.06
7 hr	2.31±0.06	2.59±0.05	2.36±0.07
Total for 7 hrs	14.14±0.11	15.00±0.09	14.12±0.13

*See footnotes to Table 10.

NITROGEN UTILIZATION IN RATIONS WITH SUNFLOWER MEAL BY SHEEP

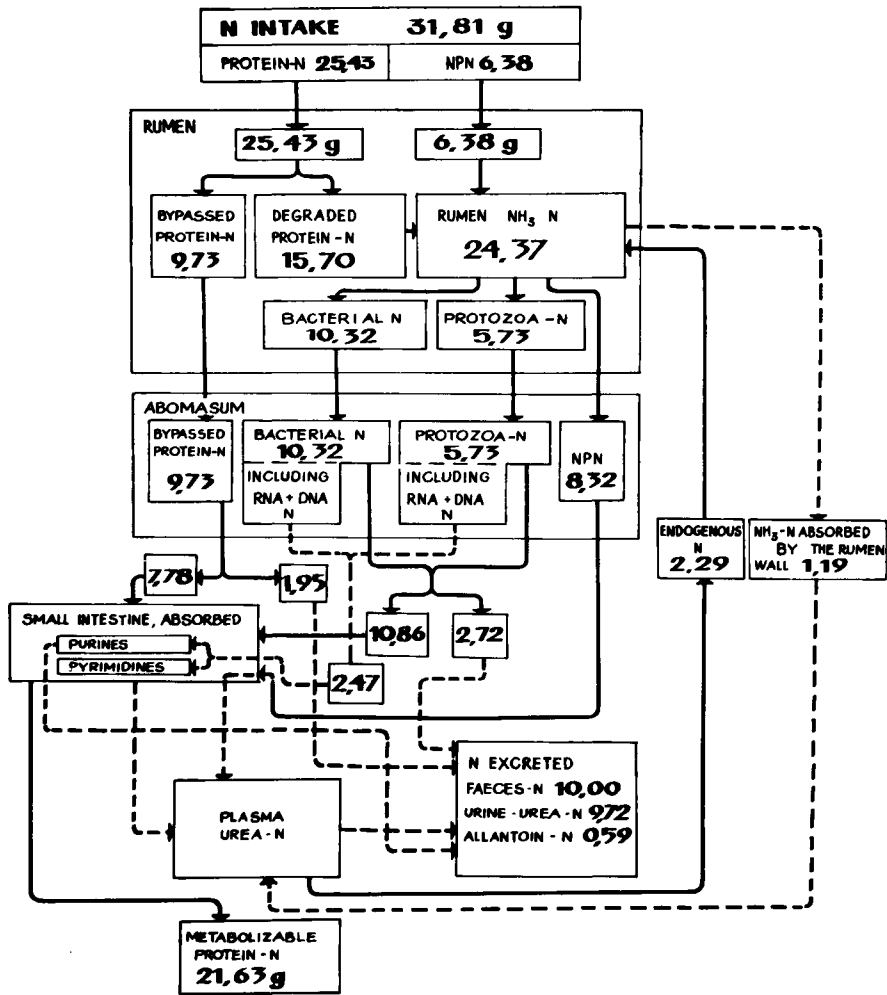


Fig. 2.

NITROGEN UTILIZATION IN RATIONS WITH SOYBEAN MEAL BY SHEEP

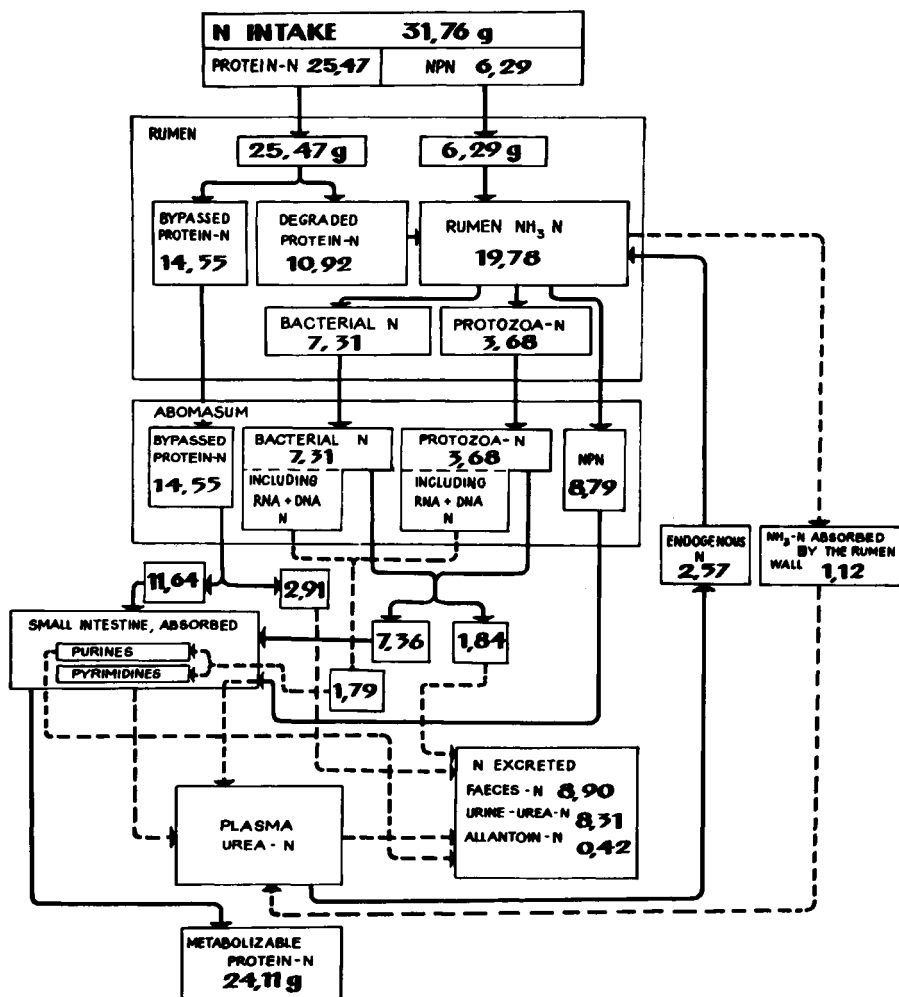


Fig. 3.

Recent Advances in our Understanding of the Significance of Rumen Fermentation

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1. INTRODUCTION

Productivity in ruminants in terms of the output/input ratio has dramatically increased in most European countries during the past decades. This could be achieved by a simultaneous improvement of methods of breeding and feeding. At present, a further improvement by means of feeding seems somewhat impeded because of a limited knowledge of the process of microbial fermentation in the forestomachs and how to manipulate this advantageously.

In recent years a number of review papers on various aspects of rumen fermentation were published (Ørskov, 1975; Bergen and Yokoyama, 1977; Chalupa, 1977; Tamminga et al., 1978; Harfoot, 1978). The majority of these papers emphasize one aspect of rumen fermentation without trying to interrelate the various aspects such as protein, carbohydrate and lipid metabolism. In this paper it will be attempted to consider various aspects of rumen fermentation, its significance in ruminant feeding and ways to manipulate rumen fermentation.

2. DEGRADATIVE PROCESSES IN THE RUMEN

Rumen fermentation includes two major processes: microbial degradation of dietary compounds (mainly carbohydrates and proteins) and the synthesis of organic macromolecules in microbial mass (mainly proteins, nucleic acids, carbohydrates and lipids). Both processes are influenced by the rate of passage of digesta through the forestomachs.

2.1 Rate of passage of digesta through the forestomachs

Ruminal digesta seems best regarded as containing three components: long feed particles, small feed particles and fluid. The rate of passage of these components or rumen turnover is often defined as the fractional outflow rate (usually expressed as percentage or proportion leaving the rumen per hour). Measurements of such fractional outflow rates are performed with indigestible markers, either soluble such as polyethylene glycol (PEG) or Cr-EDTA, or insoluble markers which strongly adhere to food particles such as Ru-phenanthroline or other rare earth metals.

Accurate and reliable measurements of fractional outflow rates are difficult to obtain. Steady state conditions are not always achieved, the marker techniques have limitations, appropriate sampling from the rumen is difficult, especially with respect to food particles, and the validity of the compartmental models in such studies may be questioned (Ellis *et al.*, 1979).

Turnover rates from the reticulo-rumen were found to differ between water and dry matter (Groven and Williams, 1973). In sheep fed lucerne chaff, fractional outflow rate of dry matter averaged 81 % of that of water. Increasing the intake increased the fractional outflow rate of both water and dry matter (Groven and Williams, 1977) in sheep. In sheep fed brome grass pellets the difference between outflow rates of fluid and dry matter, measured with ^{103}Ru as a marker, varied from 58 to 79 % of that of fluid (Kennedy et al., 1976; Kennedy and Milligan, 1978). Little information is available on fractional outflow rates of the different components in large ruminants such as dairy cows. In a recent experiment (Hartnell and Satter, 1979) the fractional outflow rate of long particles, small particles and fluid was estimated in dairy cows. Variation in outflow rate for the various components due to level of intake or roughage/concentrates ratio was found to be small. Outflow rates for liquid, grain and long hay averaged 0.087 ; 0.045 and 0.035 h^{-1} respectively. These outflow rates seem low, particularly for rumen fluid. It was found in dairy cows (Tamminga et al., 1978) that rumen fluid outflow rates increased with intake and that the intake of long roughage had a larger effect than the intake of ground and pelleted concentrates. At intakes of 15 kg of dry matter per day and higher, liquid outflow rates varied between 0.16 and 0.20 h^{-1} , about twice as high as those measured by Hartnell and Satter (1979) at comparable intakes.

It is beyond doubt that the ingestion of long roughage stimulates saliva production (Kaufmann, 1976), which is thought to increase the fractional outflow rate of rumen fluid as was the case after the infusion of artificial saliva in sheep (Harrison et al., 1976) and mineral salts in steers (Rogers et al., 1979). Because of the increased outflow rate of fluid, small particles may become more or less washed out of the rumen and the outflow rate of solids will also increase, hence decreasing the average retention time of food particles in the rumen.

2.2 Degradation of carbohydrates in the rumen

A simple classification of carbohydrates in ruminant feeds is a distinction between structural carbohydrates, non-structural carbohydrates and free sugars (Table 1). Important characteristics of structural carbohydrates are insolubility, cellulose and hemicellulose being major components and the majority of their monomers linked by β -glycosidic bonds. Non-structural carbohydrates differ from structural carbohydrates; they are more soluble and their main polysaccharides are starches or fructosans in which the majority of the monomers are linked by α -glycosidic bonds. Starches are mainly found as storage carbohydrates in grains and certain tubers (potatoes, cassava). Fructosans are found in significant amounts in forages (fresh grass, grass hay). Free sugars or soluble carbohydrates are either present as monomers or oligomers containing up to 4 or 5 monomers. They may be present as storage carbohydrates (saccharose in sugar beets and fodder beets).

Analysing feedstuffs according to the classification in Table 1 is laborious and time-consuming. In practice, simplified analytical classifications are used. The oldest, but not very accurate method is a distinction between crude fiber, roughly representing structural carbohydrates, and N-free extracts, roughly representing non-structural carbohydrates. Major disadvantages of this classification are that the analytical procedure for crude fiber is rather empirical and that N-free extracts are not determined as such, but calculated by subtracting all other fractions from the total. A procedure becoming increasingly popular is to measure soluble carbohydrates and starch and to analyse the remaining fibrous fractions according to methods developed by Van Soest (1966), separating the fibrous fractions or neutral detergent residue (NDR) in acid detergent fiber (ADF), mainly containing hemicellulose and acid detergent residue (ADR). The latter can be

analysed further for its main components cellulose, lignin and acid insoluble ash. However, this method is also rather complicated, laborious and also has limitations.

Degradation of carbohydrates differs between various classes. Degradation of structural carbohydrates requires a lag phase during which the bacteria adhere to the insoluble substrate and the appropriate enzymes are being synthesized in sufficient concentrations (Mertens, 1977). During this lag period an extra-cellular slime layer is formed in many strains of rumen bacteria, possibly necessary to facilitate the adhesion to feed particles (Cheng et al., 1977). Development of this layer is promoted by soluble carbohydrates and it was suggested (Demeyer, 1980) that this explains why small amounts of soluble carbohydrates promote the degradation of structural carbohydrates.

Non-structural carbohydrates do not require a lag phase and their degradation is rapid and starts immediately after feeding. It is assumed (Johnson, 1976) that free sugars are degraded almost instantaneously, followed by a rapid degradation of other non-structural carbohydrates such as fructosans and starches.

To what proportion carbohydrates are degraded in the forestomachs depends on the amount of carbohydrates which is potentially degradable, on the rate of degradation and on the rate of passage of carbohydrates through the forestomachs. Only few studies are available on the proportion of digestion taking place in the forestomachs for the various classes of carbohydrates. In reviewing the available data (Tamminga, 1979) it appeared that usually a proportion of over 90 % of the digestion of cellulose, hemicellulose, pectic substances and free sugars took place in the forestomachs. The proportion of the digestion of starch and fructosans taking place in the forestomachs was somewhat lower and ranged between 0.75 and 1.00 for starch and between 0.65 and 0.75 for fructosans.

Of the digestible structural carbohydrates, the proportion not digested in the forestomachs is thought to be digested by microbial fermentation in the hindgut. A negative relationship was found (Ulyatt et al., 1975) between the proportion of structural carbohydrates totally digested and the proportion digested in the hindgut. Digestion of non-structural carbohydrates, starch in particular is not restricted to microbial fermentation in forestomachs or large intestine, but may also occur in the small intestine, but not unlimited. It was estimated (Ørskov, 1977) that the capacity of the small intestine to digest starch is limited to some 20 % of the metabolisable energy (ME) requirement in lambs, calves and steers, but to only 11 % of the ME required by lactating dairy cows. The absorption capacity for glucose was estimated somewhat higher, up to 25 % of the ME required in lambs, calves and steers and up to 14 % of the ME required by lactating dairy cows.

2.3 Degradation of protein in the forestomachs

A workable classification of crude protein ($CP = N \times 6.25$) is shown in Table 2. Soluble and insoluble CP both contain true protein and non-protein-N (NPN). The NPN within soluble CP may be present as a natural constituent (amino acids, amides, amines, nitrates, nucleic acids) or may have been added (urea). Within insoluble CP, NPN may also be present as a natural constituent of the feed (lignified N) or due to supplementation (biuret, iso-butylidurea, ureaphosphate).

As was the case with carbohydrates, it has become widely accepted that soluble CP is degraded almost instantaneously, no matter whether it contains true protein or NPN. Consequently, a classification with practical potential is a description in soluble CP, lignified or ADF bound CP and insoluble CP. A wide variation in all these CP components was reported (Sniffen et al., 1979). Of the three components, insoluble but potentially degradable CP usually forms a major part. Actual

degradation of this component depends on the rate of degradation and rate of passage through the forestomachs. The rate of degradation varies, not only between feedstuffs (Crawford *et al.*, 1978), but also with the diet (Ganev *et al.*, 1979; Zinn and Owens, 1980). With roughage-rich diets the rate of degradation appears higher than with concentrate rich-diets (Ganev *et al.*, 1979), resulting in less dietary protein bypassing the rumen when roughage-rich diets are fed (Zinn and Owens, 1980). This is counterbalanced to some extent by the decreased rumen-retention time of the protein, particularly ground protein-rich supplements (Ganev *et al.*, 1979), when roughage-rich diets are fed.

It becomes clear that the extent of protein degradation is not a single property of a feed, but that it also depends on the other dietary components and on the level of intake.

2.4 Degradation of lipids in the forestomachs

Extensive reviews on lipid metabolism in the rumen were published recently (Noble, 1978; Harfoot, 1978). From these the following conclusions can be drawn: Hydrolysis of triglycerides, galactolipids (a major component of the lipid fraction in roughages) and phospholipids take place in the rumen. Both microbial enzymes and plant enzymes may be involved in this degradation process. Of the liberated long-chain fatty acids unsaturated acids become biohydrogenated. In this process of biohydrogenation feed particles appear to play an important role (Harfoot, 1978). It is suggested that the long-chain fatty acids become adhered to feed particles and are subsequently hydrogenated by extracellular bacteria enzymes.

3. SYNTHETIC PROCESSES IN THE RUMEN

The synthetic processes in the rumen can be regarded as the formation of macromolecules in (microbial) biomass. This biomass formation requires precursors as well as a source of energy. The latter must be available in a biological form, i.e. stored in the terminal pyrophosphate bond of adenosinetriphosphate (ATP). The major components of the biomass synthesized in the rumen are proteins, nucleic acids, carbohydrates and lipids.

3.1 The synthesis of carbohydrates

Rumen microbes may contain substantial amounts of carbohydrates (McAllan and Smith, 1974; Czerkawski, 1976). Shortly after feeding concentrate-rich diets, the carbohydrate content of microbial cells rises considerably and values of up to 30 % of the microbial dry matter were reported (Czerkawski, 1976). A major part of the bacterial carbohydrates will then be present in the slime layer, surrounding the bacteria (Cheng *et al.*, 1977). Protozoa are also known to accumulate polysaccharides inside their cells (Hungate, 1966) as a storage material. The main precursors for the synthesis of microbial carbohydrates are presumably monosaccharides resulting from the degradation of dietary carbohydrates.

3.2 The synthesis of proteins and nucleic acids

A large proportion of the biomass is crude protein. In isolated bacteria and protozoa the crude protein content may vary between 30 and 70 % (Smith, 1975). A major part of this variation is caused by variation in ash content (Smith, 1975) and carbohydrate content (Czerkawski, 1976). Part of the crude protein in bacteria and protozoa is present as nucleic acids usually 10 to 20 %, a percentage which is somewhat higher in bacteria than in protozoa (Tamminga, unpublished results). This is in agreement with the higher amino acid N/total N ratio found in protozoa compared with bacteria (Tamminga, 1975).

Precursors for the synthesis of amino acids, the building stones of protein and for the synthesis of nucleic acids are either preformed amino acids or intermediates and end products of the degradation of carbohydrates and proteins or NPN. Up to some 50% of the amino acids in microbial protein may result from direct incorporation of preformed amino acids (Nolan, 1976). For some strains of rumen bacteria and for protozoa preformed amino acids are essential. Transport of these preformed amino acids inside bacterial cells seems to be as peptides rather than as free amino acids (Prins *et al.*, 1979). Protozoa ensure their supply of preformed amino acids by the engulfment and digestion of bacteria (Coleman, 1975; Coleman and Sandford, 1979).

Protein synthesis requires comparatively large amounts of energy, particularly the linkage of monomers together in a peptide chain. Recent estimates (Hespell and Bryant, 1979) suggest 5 moles of ATP for each peptide bond. As a comparison the formation of 100 g of protein from monomers (i.e. amino acids) requires 4.55 moles of ATP whereas the formation of 100 g of polysaccharides from monomers (glucose) requires only 1.23 moles of ATP. The synthesis of the nucleic acids RNA and DNA was estimated to require 1.67 and 2.14 moles of ATP per 100 g respectively (Hespell and Bryant, 1979).

3.3 The synthesis of lipids

Both bacteria and protozoa are capable of *de novo* synthesis of long-chain fatty acids. On the other hand bacteria as well as protozoa can take up long-chain fatty acids from their surrounding medium and incorporate them in their own cellular lipids (Harfoot, 1978).

Little is known on the proportion of microbial structural lipids which result from direct incorporation of dietary long-chain fatty acids or from *de novo* synthesis, but recent research (Demeyer *et al.*, 1978) suggests that the amounts directly incorporated may be greater than the amounts synthesized *de novo*.

3.4 Microbial growth efficiency in the rumen

Recently extensive reviews were devoted to this subject (Hespell and Bryant, 1979; Harrison and McAllan, 1980). From these reviews a number of principles can be extracted. Certain nutrients (i.e. NH_3 , amino acids, sulphur, micro-nutrients, co-factors) may limit microbial growth. If the supply of nutrients is adequate, microbial growth is limited by the supply of energy. Even under conditions of an adequate nutrient supply energetic efficiency of microbial growth varies.

If microbial growth is considered as the formation of biomass then energy (ATP) is required for two processes. Firstly ATP is needed for maintenance. Compounds of this maintenance requirement were summarised by Hespell and Bryant (1979) and include processes such as motility, turnover, production of extracellular macromolecules (proteins, carbohydrates), active transport, lysis and resynthesis of cellular compounds, etc. In addition to an ATP requirement for maintenance, ATP is needed for the synthesis of macromolecules constituting the various cell components. The ratio in which ATP is required for both processes is largely determined by the growth rate, which in turn depends on the rate with which ATP becomes available. Important aspects in this respect are the amount of ATP generated per unit of time and per unit of substrate. In Table 3 a qualitative description is given of the ATP generation of the degradation of various dietary components.

From Table 3 it becomes evident that the efficiency of biomass formation is influenced by the composition of the fermented substrate. There is some evidence (Tamminga, 1979a; Hagemeister *et al.*, 1980) that with diets either almost entirely based on long roughage or with diets almost entirely based on concentrates,

microbial growth becomes less efficient.

Not only the composition of the fermented substrate influences the efficiency of microbial growth. So does the composition of the biomass itself, because the formation of the various micromolecules (proteins, nucleic acids, carbohydrates, lipids) requires different amounts of ATP (Hespell and Bryant, 1979).

A factor not yet explored extensively is the possible effect of the pH in the rumen. In vitro it was shown recently (Kirstner et al., 1979) that three strains of rumen bacteria tested (*Butyrivibrio fibrisolvens*, *Streptococcus bovis*, *Megasphaera elsdenii*) showed rather distinct pH optima at which their specific growth was maximal. An interesting observation in this respect was that with *B. fibrisolvens* growth rate approached zero at pH 5.5, whereas with *S. bovis* and *M. elsdenii*, growth rates did not approach zero before the pH had dropped to 4.5.

An important phenomenon which influences the growth rate is the fractional outflow rate, particularly of rumen fluid (Harrison and McAllan, 1980). Increased fractional outflow rates were shown to increase the energetic efficiency of microbial growth, both in vitro and in vivo. This must be due to an increased washing out, because increasing the substrate concentration in vitro had no effect other than to increase the concentration of the bacteria (Isaacson et al., 1975). Increasing the dilution rate in these experiments also meant an increased supply of substrate, but under these conditions the concentrations of bacteria remained unchanged. Increasing the dilution rate in vivo (Harrison et al., 1975; 1976), without altering the feed intake and thus keeping the substrate supply unchanged, also increased the efficiency of microbial growth in the rumen. Increasing the feed intake will also increase the fractional outflow rate, but this does not seem to effect the efficiency of microbial growth (Tamminga, 1978). The range over which the fractional outflow rate is increased may be important in this respect. It was shown (Harrison and McAllan, 1980) that at fractional outflow rates above 0.10 a further increase hardly had any effect on the efficiency of microbial growth.

4. THE EFFECT OF RUMEN FERMENTATION ON THE NUTRITIVE VALUE OF THE INGESTED NUTRIENTS

For the host animal, rumen fermentation may result in losses or gains of the potential nutritive value ingested. Three types of products result from rumen fermentation, non-fermented dietary components, microbial biomass and microbial waste products.

4.1 Non-fermented dietary components

Amongst these components are undegraded crude protein, undegraded structural carbohydrates, undegraded non-structural carbohydrates and undegraded lipids or long chain fatty acids.

The nutritive value of undegraded protein depends on its intestinal digestibility and on its amino acid composition. Part of the undegraded crude protein will be lignin-bound N, which is undigestible and therefore without nutritive value for the host animal. If the diet is supplemented with slow release NPN compounds such as isobutylidiurea, acetylurea or biuret, an important part of the supplement may escape degradation in the rumen (Kaufmann and Hagemeister, 1973; Krawilitski et al., 1974; Tamminga, unpublished results). If intestinal digestion is possible, the resulting ammonia may become of some value to the microbes after conversion to urea and back transfer to the rumen, but otherwise it has no nutritive value.

Little is known on the intestinal digestibility of the true protein in the crude protein bypassing the rumen. Jarriige *et al.* (1978) analysed the faecal excretion of N with multiple regression techniques and related it to insoluble N ingested, apparently digestible organic matter ingested and organic matter excreted in the faeces. The faecal N related to the insoluble N ingested was suggested to originate from the 65% of the insoluble dietary N thought to pass the rumen unchanged. Their calculations led to true digestibility figures for N escaping degradation in the rumen varying between 50 and 95%. Other researchers (Schwartz and Kaufmann, 1978) measured increased faecal output of N resulting from abomasal infusions of different protein supplements and regarded the increase as the non digestible part of the infused protein. They found only small differences between the different supplements and accepted an average value of 85%. Both approaches, however, do not take into account a possible degradation of protein in the large intestine, by which the true nutritive value of undegraded feed protein may become slightly overestimated.

Little is known on the amino acid composition of the undegraded dietary protein. Important differences were found in amino acid composition of total protein and soluble protein in a large number of feedstuffs (MacGregor *et al.*, 1978), suggesting that protein bypassing the rumen may differ in amino acid composition from the protein ingested. Evidence that the amino acid profile of undegraded feed protein entering the small intestine differs from that in the protein ingested was also obtained *in vivo* (Tamminga, 1979b). This seems particularly true for methionine (Smith and Mohamed, 1977).

Carbohydrates bypassing the rumen are subjected to enzymatic digestion in the small intestine and microbial degradation in caecum and colon. Enzymatic digestion is practically restricted to non-structural carbohydrates. The capacity of the small intestine to hydrolyse non-structural carbohydrates and to absorb the resulting glucose seems however, limited (Ørskov, 1977). A limited hydrolysis of starch may result from an intestinal pH below that optimal for pancreatic alpha amylase (Wheeler and Noller, 1977). This decreased intestinal digestion of starch seemed not to be compensated by an increased fermentation in the hind gut, because a low intestinal pH resulted in a high starch excretion in the faeces.

Fermentative digestion in the hind gut may include both structural and non-structural carbohydrates. The site of intestinal digestion and absorption affects the nutritive value of the digested carbohydrates. Fermentation of carbohydrates in the hind gut resulting in volatile fatty acids as nutrients for the host animal and fermentation losses, lowers the nutritive value of carbohydrates somewhat compared with carbohydrates digested and absorbed (mainly as glucose) from the small intestine.

Dietary lipids are subjected to a normal enzymatic digestive process in the small intestine. The fact that the lipids arrive in the small intestine mainly as free fatty acids rather than as triglycerides does hardly affect its nutritive value for the host animal. The formation of Ca or Mg salts of fatty acids before reaching the small intestine may have a negative effect on their absorption and hence on their nutritive value for the host animal.

4.2 Microbial biomass

Information on the nutritive value of biomass for the host animal is limited and virtually restricted to N-containing compounds. Figures on digestibility of these compounds in the small intestine of ruminants are difficult to obtain. Most data suggest a rather constant figure of between 70 and 85% (Schwartz and Kaufmann, 1978; Verité *et al.*, 1979), but there is evidence that this may vary

somewhat with certain dietary conditions (Smith, 1975; Smith et al., 1976).

The amino acid composition of microbial protein is rather constant (Weller et al., 1957; Purser and Buechler, 1966; Meyer et al., 1967; Hoogenraad and Hird, 1970; Tamminga, 1965; Czerkawski, 1976), although some differences were found between bacteria and protozoa. It is as yet uncertain to what extent protozoa contribute to the N entering the small intestine, but most experiments suggest that this contribution is considerably less than the contribution of bacteria (Weller et al., 1974; Harrison et al., 1979).

The amino acid composition of microbial protein closely resembles the amino acid composition of animal protein in meat and milk (Hagemeister, 1978), suggesting a higher nutritive value than most of the dietary proteins included in ruminants diets and bypassing the rumen.

4.3 Microbial waste products

Microbial waste products include volatile fatty acids, carbondioxide, methane, ammonia and fermentation heat. Only volatile fatty acids have a nutritive value for the host animal. Theoretically some differences exist in the efficiency with which the different volatile fatty acids are utilised for maintenance (Armstrong, 1969) but in vivo these differences seem small (Ørskov et al., 1979). For production, i.e. lipogenesis, the efficiency of utilisation was claimed to fall with an increasing proportion of acetate (Armstrong, 1969), which seems difficult to explain and which does not seem to be the case under all circumstances (Ørskov et al., 1979).

5. WAYS TO MANIPULATE RUMEN FERMENTATION

Essentially three ways are possible to manipulate rumen fermentation to the host animal's advantage. Firstly, the composition of the microbial waste products (volatile fatty acids, methane) can be altered. Secondly, it is possible to decrease the degradation of dietary ingredients and let them bypass the rumen after which they can be subjected to the host animal's enzymatic digestion process, thus avoiding fermentation losses. Thirdly, rumen fermentation can be manipulated in such a way that microbial growth becomes more efficient, resulting in more biomass available for the host animal.

A number of technical ways to manipulate rumen fermentation are possible, mainly with respect to level and/or pattern of feeding, composition of the diet, processing the diet and supplementing the diet with active agents.

5.1 Changing the level of feeding

Increasing the feeding level often increases the fractional outflow rate from the rumen, both of food particles and of rumen liquor, as was discussed earlier (section 2.1.). This may result in a shift of the site of digestion from the rumen towards the lower gut, thus limiting the amount of substrate available for microbial biomass production in the rumen. This may, however, be counterbalanced by a more efficient microbial growth, so that the net effect remains small. A more pronounced effect may be expected for the proportion of a nutrient bypassing the rumen. It was shown that at high feeding levels of corn based diets substantial amounts of starch escape rumen fermentation (Waldo, 1973), the advantage of which seems limited because of limitations in the capacity of the small intestine to hydrolyse starch and to absorb the resulting glucose (Ørskov, 1977). Increasing the bypass of protein by increasing the feeding level seems also possible. (Tamminga et al., 1979; Ørskov and McDonald, 1979; Zinn and Owens, 1980).

The effect of the level of feeding on the end products of rumen fermentation is not well documented. However, a tendency for acetate to decrease and propionate to increase with an increasing level of feeding has been observed (Sutton et al., 1977; Galyan et al., 1979).

Results on the effect of level of feed intake on the efficiency of microbial growth and microbial protein production are very limited and the results are variable (Tamminga, 1978; Zinn and Owens, 1980).

5.2 Changing the feeding procedure

Ruminant diets usually contain long roughage (hay, silage, straw) and concentrates (grains, by-products of the feed industry, tubers or roots rich in starch). The long roughage is necessary to sustain a structural layer in the rumen, which separates the fluid phase at the bottom and the gaseous phase at the top of the rumen. This layer stimulates rumen motility, rumination and salivary production. It is therefore advised in the Netherlands that at least one-third of the dry matter ingested by ruminants should be long roughage.

With high production, large quantities of concentrates need to be fed and rumen fermentation may become disturbed by disruption of the structural layer and by a high rate of fermentation of (non-structural) carbohydrates. These negative effects can be counterbalanced to a certain degree by altering the sequence in which long roughage and ground concentrates are fed or by increasing the frequency of feeding.

Very little information is available on the effect of sequence of feeding. Voigt et al. (1978) found a positive effect on rumen fermentation when the roughage part of the diet was fed before the concentrate part. With feeding the roughage part first the drop in rumen pH shortly after feeding was less severe and the proportion of acetate in the VFA remained higher. Although the total flow of N to the small intestine remained unchanged, a shift was observed in the proportion of microbial protein and undegraded feed protein. Feeding the roughage part of the diet first caused more undegraded feed N and less microbial N entering the small intestine than when the concentrates were fed first, which is somewhat unexpected and difficult to explain.

Increasing the frequency of feeding has also been advised as a means of preventing fermentation disturbances in the rumen (Kaufmann, 1976). Feeding the concentrate part of the diet in 12 equal portions compared with 2 equal portions showed a higher acetate to propionate ratio and a pH with much less diurnal variation. Similar observations were made by Van der Honing et al. (1976) and Jensen and Wolstrup (1977).

Little is known on the effect of frequency of feeding on N metabolism in the rumen. No differences in duodenal N flow were observed in sheep, if chopped dried grass was fed once daily or continuously (MacRae et al., 1972). Increasing the feeding frequency of a diet based on artificial dried and pelleted grass supplemented with mixtures of milled barley and sucrose tended to increase the production of microbial protein in the rumen (Al Attar, et al., 1976). Total N entering the small intestine of dairy cows after feeding low N diets containing large amounts of extruded corn was also increased after more frequent feeding (Tamminga, 1979a). When feeding more normal diets consisting of sufficient long hay and concentrates with a more normal N content, differences in intestinal N flow due to frequent feeding were much smaller, but still a tendency was found of an increased duodenal N flow after frequent feeding (Tamminga, unpublished results).

A beneficial effect of an increased frequency of feeding seems restricted to unfavourable dietary conditions such as an extreme ratio between structural and non-structural carbohydrates or with extremely low dietary N levels.

5.3 Changing the composition and physical form of the diet

Most frequently induced changes in chemical composition of the diet in practical feeding include changing the ratio between structural and non-structural carbohydrates, changing the protein content of the diet, supplementing the diet with NPN or supplementing the diet with lipids. The most rigorous and most often applied way of changing the physical form of the diet is grinding, the application of which is usually restricted to the concentrate part of the diet. Feeding more concentrates therefore often results in both a change in the physical form of the diet and in an increase of the proportion of non-structural carbohydrates. This results in a decrease in ruminal pH, an increase in the proportion of propionate if starch is the main component of the non-structural carbohydrates (Van Vuuren *et al.*, 1979), an increase in the proportion of both propionate and butyrate if large amounts of free sugars are present (Marty and Preston, 1970; Sutton 1979), sometimes a decrease in cellulolytic activity (Ørskov, 1976, Stewart, 1977), a decrease in fractional outflow rate of rumen liquor (Tamminga *et al.*, 1978), an increase on the carbohydrate content of rumen micro-organisms (McAllan and Smith, 1974; Czerkawski, 1976) and under certain conditions a decrease in the efficiency of microbial growth and microbial protein production (see Tamminga, 1979). Feeding more long roughage has of course the opposite effect.

With respect to the protein content of the diet a minimum amount of ruminal degradable protein, resulting in a minimum NH_3 level to sustain maximum fermentation or maximum microbial protein synthesis seems required. Values of 235 mg/l for maximum fermentation (Mehrex *et al.*, 1977) and 50 mg/l for maximum microbial protein synthesis (Satter and Slyter, 1974) were reported. However, recently it was questioned (Hespell and Bryant, 1979) if the latter value of 50 mg/l can inhibit microbial growth. It was suggested that growth inhibition was due to a lack of preformed amino acids rather than due to a lack of NH_3 . No negative effects of a high NH_3 concentration on rumen fermentation have been observed so far.

Preformed amino acids as a N source for microbial growth resulted in a higher yield of microbial protein than with the NPN source urea (Maeng and Baldwin, 1976), suggesting that replacing dietary protein by NPN may decrease the supply of microbial protein to the host animal.

Supplementing the diet with fats or fatty acids may also influence rumen fermentation. The site of digestion of organic matter was shifted from the forestomachs to the lower gut if the diet of sheep, consisting of long hay and concentrates, was supplemented with lipids (Knight *et al.*, 1978). Within the VFA the proportion of propionate is usually enhanced after the addition of saturated or unsaturated fats or fatty acids (Van Nevel *et al.*, 1971; Kowalczyk *et al.*, 1977; Binet *et al.*, 1980) with a concomitant reduction in CH_4 -production (Van Nevel *et al.*, 1971; Henderson, 1973; Tamminga, 1980). Cellulose digestion may also become inhibited (Kowalczyk *et al.*, 1977). It is not clear whether this is a result of the inhibition of certain strains of bacteria, the inhibition of certain strains of protozoa, or both. There is some evidence that protozoa may be specifically inhibited by lipids (Knight *et al.*, 1977). This is also in line with the finding that lipids lower the NH_3 content in the rumen (Kowalczyk *et al.*, 1977), a phenomenon also observed in defaunated animals. Finally, the observation was made that the production of microbial protein became more efficient, but the advantage of this was levelled down by less organic matter being fermented and hence less microbial growth occurring in the forestomachs (Knight *et al.*, 1977).

Our own observations (Tamminga, unpublished results) in experiments in which concentrates were supplemented with tallow (up to 12%) and fed to dairy cows largely confirm the above pattern. Lipid supplementation increased propionate decreased the CH_4 production *in vivo*, decreased the fractional outflow rate of rumen fluid and decreased the NH_3 content. No consistent effect on rumen pH was observed.

5.4 The effect of processing

Various methods of processing ruminant diets with the aim of improving ruminant production were developed in recent years (Hale, 1975; Ørskov *et al.*, 1978). Methods causing the largest effects on rumen fermentation include grinding, heat treatment and treatment with chemicals.

Grinding results in smaller particles, with a larger total surface area, thus facilitating microbial attack and increasing the rate of fermentation, which usually increases the proportion of propionate in the VFA. Fractional outflow rate is affected by grinding, but the various fractions in different ways. Grinding as such, reducing the particle size, is expected to increase the outflow rate of the ground material itself, but grinding also reduces the salivary production, which will decrease the fractional outflow rate of rumen fluid. Since small feed particles are partly more or less suspended in the fluid, reducing the fractional outflow rate of the fluid will probably also reduce the outflow rate of small particles. Little is known on the effect of particle size on microbial growth.

A rather large number of dietary ingredients used in ruminant feeding are subjected to some form of heat treatment. Protein supplements originating from oil seeds or from legumes are often heated in order to destroy anti-nutritional factors. In stored hay or silages heat may develop. Some products are dried artificially and undergo heat treatment.

Whether the effect of heat treatment of protein is an advantage or a disadvantage for ruminants, depends on the conditions. If the effect of the heat treatment is restricted to denaturation of the protein, making it less soluble and probably less susceptible for microbial attack, without causing negative effects on the nutritive value of the protein, the amount of digestible protein bypassing the rumen will increase. Particularly for high producing animals this extra bypass protein may fill the gap between intestinal supply and tissue demand. Negative effects on the nutritive value of the protein may be expected if the temperature is very high or when the protein is subjected to moderate temperatures for longer periods (Goering, 1976). The first situation may occur in artificial drying, when most of the water is evaporated; the second situation may occur in silages or hay where a moderate to high temperature may be present for a long period. The presence of carbohydrates, causing Maillard reactions also reduces the nutritive value of protein (Ford, 1975). Although the possible positive effect of heat treatment on the nutritive value of protein for ruminants was recognized a long time ago (Chalmers *et al.*, 1954; Tagari *et al.*, 1962), few attempts have been made since to exploit this way of processing in ruminant feeding. The present cost of fossile energy may prevent a renewed interest in this direction.

Perhaps a more promising method of processing is treatment with chemicals. Two major developments have started. Firstly, attempts are being made to protect protein against degradation in the rumen by treatment with chemicals such as aldehydes and tannins. This subject was reviewed extensively (Chalupa, 1975; Ferguson, 1975; Barry, 1976a). Responses were most pronounced with wool growth, and did increase with an increasing content of S-containing amino acids in the

treated protein (Barry, 1976b). Production responses in growth and milk production are variable and particularly in milk production rather small as was shown in a recent review (Tamminga, 1979). The failure of a response may result from overprotection of the protein causing only more protein entering the small intestine, but not more protein being absorbed. If the intestinal protein supply is already adequate, an increased supply of bypass protein will also fail to show a response.

Another development with respect to formaldehyde treatment is to coat fat with a thin layer of protein which can subsequently be protected against microbial activity in the rumen by formaldehyde. Technically successful attempts have been made to protect polyunsaturated fatty acids against biohydrogenation in the rumen by this method (Scott and Cook, 1975), resulting in increased levels of polyunsaturated long chain fatty acids in meat and milk. However, the economic prospects of this method do not seem to be very attractive. A similar development is to protect saturated lipids by this method in order to increase the energy intake of ruminants, particularly of dairy cows in early lactation (Storrey *et al.*, 1974). It may be questioned however, if such protective measures are always necessary. Recent findings (Palmquist and Conrad, 1978) suggest that large amounts of fat can be included in the diet of dairy cows under certain dietary conditions, without showing negative effects on rumen fermentation. Recent observations in our own institute seem to confirm these findings.

A further development with respect to chemical treatment is to increase the degradation of the structural carbohydrates. Part of the structural carbohydrates is undegradable, caused by encrustation of structural carbohydrates with lignin and silica, which act as physical barriers to the rumen micro-organisms. Treatment of feeds in which high amounts of such encrusted complexes are present, such as straw and matured hay, with chemicals like NaOH or NH_3 , sometimes combined with high pressure, may increase the degradability in the rumen (Gillies, 1978). This treatment not only increases the energy supply to the host animal, but also to the rumen micro-organisms. The resulting increased microbial growth, provided sufficient N is available, will cause more protein production in the rumen and hence also increase the protein supply to the host animal. Whether processes like this are economically feasible depends on the balance between the difference in economic value of end products and raw material and the costs of the process. If the raw material has some application other than burning or plowing back, hence if it has some economic value, this balance is usually negative. Because of the increasing costs of fossil energy, which is required for this processing, the prospects of these methods seem limited.

5.5 Supplementing the diet with active agents

The interest of supplementing ruminant diets with small amounts of active substances in order to manipulate rumen fermentation is growing. Two major developments can be mentioned. One is supplementing the diet with compounds which have a positive effect on the environment of the microbes. For this purpose buffering compounds like NaHCO_3 or MgO are used (Erdman, 1980). The main effect of buffers can be achieved with diets low in structural carbohydrates. Adding buffers to these diets tends to shift the VFA proportions towards acetate, it may prevent the ruminal pH to fall below 6.0, it may increase the fractional outflow rate of rumen fluid and associated with the latter may have a positive effect on the energetic efficiency of microbial protein production in the rumen (Erdman, 1980; Harrison *et al.*, 1976).

A second development is supplementing the diet with pharmaceuticals or other active chemical compounds, in order to manipulate rumen fermentation. It seems

reasonable to assume that the mode of action of such compounds is on the micro-organisms rather than on their environment.

Various classes of such compounds were reviewed by Chalupa (1977), who discussed propionate enhancers, CH_4 -inhibitors, deaminase inhibitors and urease inhibitors. A problem in the usefulness of such compounds is adaptation of the rumen micro-flora, due to which it often shows only a short term effect. Adaptation has been observed with a number of CH_4 -inhibitors, if tested under in vivo conditions (see Tamminga, 1976; see Van Nevel & Demeijer, 1976).

A widely used compound which does not show adaptation is Rumensin, a coccidiostat which has been used for a long time in poultry nutrition. Its effect on rumen fermentation includes a shift in the molar proportions of the VFA towards propionate (Raun, 1978), a decrease of protein degradation causing an increased flow of undegraded dietary protein to the small intestine (Van Nevel and Demeyer, 1977; Poos et al., 1979) but also a decrease in microbial protein synthesis (Van Nevel and Demeyer, 1977; Poos et al., 1979; Allen and Harrison, 1979). Evidence was obtained in vitro that Rumensin selects strains of rumen bacteria in two ways: firstly in favour of propionate producing strains and secondly against H_2 and formate producing strains, which will also inhibit CH_4 -formation (Cheng and Wolin, 1979).

The ultimate aim of the use of such compounds is to improve animal production. Some CH_4 -inhibitors showed a positive effect in growth trials (see Tamminga, 1976; Van Nevel & Demeijer, 1976). The effect of Rumensin is also positive in growth trials and very consistent. Improvements in the feed utilisation of some 10% are often reported if the diet is supplemented with Rumensin (Raun, 1978). In recent years not only Rumensin was discovered as an agent capable to manipulate rumen fermentation, but other compounds, particularly polyether based antibiotics, showed effects as well (Bartley et al., 1979). It may therefore be expected that in the near future more active agents by which rumen fermentation can be manipulated and animal performance can be improved, will be developed.

SUMMARY

Microbial fermentation in the forestomachs of ruminants contains simultaneously occurring degradative and synthetic processes. The extent of degradation of various dietary ingredients depends on rate of degradation combined with rate of passage. The latter differs between long particles, small particles, and rumen liquor, but increases with an increasing level of food intake.

Rate of degradation of carbohydrates differs between various classes of carbohydrates. Free sugars show the highest rate of degradation, structural carbohydrates the lowest, with non-structural polysaccharides in between.

Rate of degradation of protein also varies. Soluble proteins and most NPN sources are degraded almost instantaneously. A large but varying proportion of the insoluble protein is degraded at a slower but differing rate, the remaining part is undegradable. The rate of degradation of protein is also influenced by the dietary composition. Long-roughage diets cause a higher rate of protein degradation than concentrate rich diets. The extent of protein degradation is therefore not a single property of a feedstuff, but depends also on other dietary components and on the level of feed intake.

Degradation of lipids is restricted to hydrolysis followed by biohydrogenation, of the liberated unsaturated long chain fatty acids and a further degradation of the liberated glycerol. Lipid degradation results in a mixture of free saturated long chain fatty acids.

Synthetic processes in the rumen result in the formation of biomass, containing proteins, nucleic acids, carbohydrates and lipids. Biomass formation requires precursors for the synthesis of its macromolecules as well as energy stored in ATP.

Microbial polysaccharides are synthesized mainly shortly after feeding from glucose molecules resulting from the degradation of dietary polysaccharides. Microbial protein and nucleic acids are synthesized from amino acids, part of which result from the degradation of dietary protein, the remaining part from *de novo* synthesis. Long-chain fatty acids required for the synthesis of microbial lipids are either synthesized *de novo* or originate from dietary lipids.

Energy required for biomass formation mainly results from the degradation of dietary carbohydrates into volatile fatty acids and to a much lesser extent from the degradation of dietary protein. The energetic efficiency of microbial protein production in the rumen, often expressed as the amount of microbial N synthesized per kg OM fermented in the rumen, is far from constant and is influenced by a number of factors such as chemical composition of the fermented substrate, chemical composition of the synthesized biomass, growth rate, maintenance requirements of the microbial population in the rumen, pH in the rumen, etc.

Rumen fermentation may result in losses as well as gains of the potential nutritive value ingested. A high dietary protein content usually results in protein losses, a low dietary protein content in protein gains. Degradation of structural carbohydrates is associated with losses in methane and fermentation heat, but to the host animal it means a gain because potentially undegradable nutritive value is made available to the host animal. Fermentation of nonstructural carbohydrates and free sugars, which can be digested by the digestive system of the host animal, results in loss of nutritive value of the lipid itself, but because of lipids sometimes inhibit fermentation of other dietary ingredients, structural carbohydrates in particular, they may decrease the nutritive value of the diet under certain conditions.

Three ways to manipulate rumen fermentation to the animal's advantage are discussed, viz. altering the composition of microbial waste products (mainly volatile fatty acids), increasing the proportion of a dietary ingredient bypassing the rumen and increasing the efficiency of microbial growth, particularly microbial protein production.

Technical means to manipulate rumen fermentation are changing the level or pattern of feeding, changing the composition of the diet, processing the diet and supplementing the diet with active agents.

Increasing the proportion of a nutrient bypassing the rumen can be achieved by an increased level of feeding, by heat treatment, by chemical treatment, by the addition of inhibitors of hydrolysis or other enzymatic processes and possibly by lowering the pH.

Changing the proportion of volatile fatty acids can be achieved by changing the dietary ratio between structural and non-structural carbohydrates, by supplementing the diet with lipids or by supplementing the diet with pharmaceuticals such as Rumensin.

Increasing the efficiency of microbial protein synthesis seems possible by increasing the fractional outflow rate and under certain conditions by increasing the frequency of feeding.

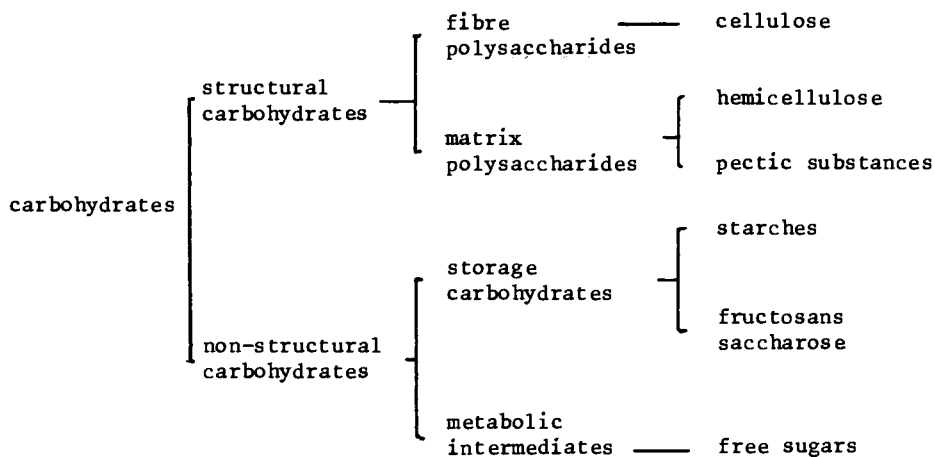
Some of these technical means to manipulate rumen fermentation have a different and sometimes opposite effect on the various processes in the rumen. Procedures to manipulate rumen fermentation must therefore be applied with care.

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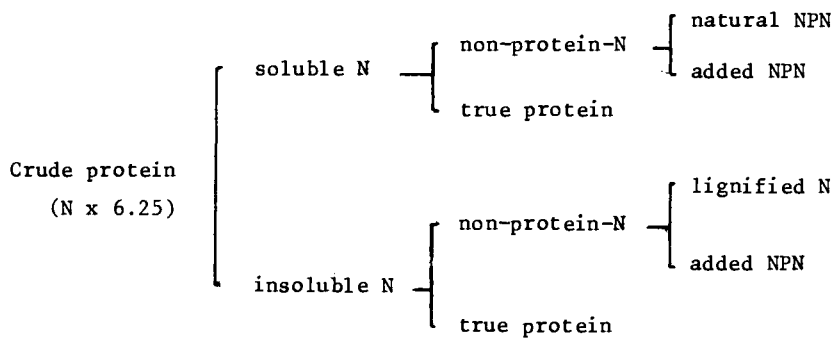
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TABLE 1. Classification of carbohydrates in ruminant feedsTABLE 2. Classification of crude protein (Nx6.25) in ruminant feeds

Adapted from Sniffen et al., 1979



Recent Advances in Understanding Protein-Energy Interrelationships in Intermediary Metabolism of Ruminants

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INTRODUCTION

'Intermediary metabolism' is usually taken to mean the processes which govern conversion of absorbed nutrients to end-products in the body. Processes which affect transformation of ingested nutrients during digestion are conventionally not included in the definition. But in the case of ruminant animals, where ingested nutrients undergo substantial microbial fermentation/metabolism before absorption takes place, it would be pedantic to exclude from this discussion those important aspects of protein/energy interrelationships which are related to digestion. The emphasis of our discussion will therefore be on metabolism of absorbed nutrients but with considerable reference to events occurring during digestion, especially in the rumen.

NEW PROTEIN SOURCES AND MEANING OF 'HIGH PRODUCTION'

This symposium is concerned with the use of new sources of protein for high levels of production of milk and meat. It would be as well therefore for the purpose of this paper to identify those new sources of protein, and to specify what are regarded as high levels of production.

One new source of protein for animal feed in the UK has been single-cell protein from fermentation of either oil or methanol (Toprina and Pruteen), but only the latter is now on the market and at a price level which only competes with fish meal. Thus essentially it is only being used as a component of non-ruminant diets, where its high quality protein is of value.

Rapeseed meal is a relative newcomer to the UK scene (but not to the Continent) and usage on a much larger scale in ruminant diets is now commonplace at levels of 5-10% inclusion.

Protected proteins, i.e. those prepared by special treatment of standard protein sources such as soya bean meal, with formaldehyde, are now being manufactured and marketed on a small scale, and have received some research attention (Oldham *et al.*, 1981). Fish meal has attracted interest for inclusion in ruminant diets because of the low degradability of some fish meal protein, in the rumen (Mehrez *et al.*, 1980), and interesting economic benefits are being found in both milk and live weight gains. Mild degrees of heat treatment of whole soya bean by extrusion in a press (Insta Pro) have been claimed to affect degradability of the soya protein (Hanson, 1980). Artificially dehydrated grass and lucerne are also subject to a degree of heat denaturation which affects the degradability of the proteins, and beneficial effects upon N retention have been demonstrated (Thomson & Beever, 1980).

For the purpose of this paper a high level of production implies a milk yield of the order of 30-35 kg/d usually requiring an ME intake of 200-240 MJ/d and a CP intake of 3500 g/d and above. For growing cattle, a high level of production is taken to mean a live weight gain in excess of 1 kg/d. Levels of 1.5 kg/d and more can be achieved with cattle at the mid-stage of their growth curve. At these levels of production and especially with lactating cows, animal performance is particularly sensitive to variation in the ratio amino acids absorbed: ME intake.

Rates of protein accretion in different breeds of cattle are now known to differ widely so that it may be expected that responses to both amount and type of protein source may show a breed effect. The British Friesian is characterised by a low maximum level of protein accretion of the order of 150 g/d so that high rates of gain imply considerable fat deposition which is energetically very expensive. The effect of sex and some hormones upon live weight gain from a given ration is now well documented, and appears to be related to small but significant shifts in the protein/fat ratio in the gains.

EFFECT OF PROTEIN INTAKE UPON RATION DIGESTIBILITY AND INTAKE

Many observations now point to substantial effects of protein intake on food intake and energy density (digestibility of food). These must be taken into account in interpretation of practical feeding trials where not only does energy status affect protein utilisation but protein intake can affect energy status.

Some of this subject will be dealt with elsewhere at this symposium but a few comments are justified here.

There are differences between growing animals and lactating cows in the pattern of response in intake or digestibility to increments in protein intake. Whereas in growing animals at maintenance protein effects on intake and digestibility are maximised at <120 g CP/kg DM (Balch & Campling, 1962; Oldham & Smith, 1980) in lactating cows ration digestibility can be sensitive to increments of protein feeding at least up to 180 g CP/kg DM (Fig. 1). It seems likely that this difference is mainly an effect of differences in level of feeding and rate of passage of food through the rumen. Increasing rate of outflow from the rumen (Ørskov & MacDonald, 1979) or level of feeding (Tamminga *et al.*, 1979) decreases the proportion of dietary protein degraded in the rumen which may mean that more protein per unit food consumed is needed to meet microbial needs, and hence maximise digestion, at high compared with low levels of feeding.

In many experiments with dairy cows DMI increases with protein supplementation (Table 1). The effect may be greater with maize silage rations (0.31 ± 0.23 kg DM/CP%) and it may also be higher with low D-value (<0.67) grass silage. Milk yield response to increased intake (Δ FCM/ Δ DMI) stimulated by protein supplementation is relatively high (2.05 mean Δ FCM/ Δ DMI; Table 1) and quite variable (s.e. ± 2.06). But the mean response is quite close to theoretical energy requirements for milk production (~5 MJ ME/kg milk or 2.0 kg milk/kg DMI when M/D is ~10 MJ/kg). This contrasts with levels of response to variation in plane of energy nutrition - usually 0.4-1 kg milk/kg increase in concentrate DMI (Broster *et al.*, 1969; Gordon, 1976, 1977; Johnson, 1977, 1979) - which are relatively low in comparison with stated ME requirements for milk production (MAFF, 1975) partly because additional concentrates may 'replace' forage and partly because only part of the increment of nutrient intake is directed towards milk production, the rest is deposited in tissue.

These observations on protein effects on intake and ration digestibility should make us aware of the need for care in interpretation of responses to variation in dietary protein input (both source and level). It is often the case that a substantial part - sometimes all - of production responses to protein have been induced by changes in energy intake rather than optimisation of energy partition towards product formation as a consequence of optimising protein status (amino acid balance).

INFLUENCE OF NITROGEN RETENTION UPON LIVE WEIGHT GAIN

It is well recognised that lean gain in growing animals requires less net energy per kg than does fat gain, but dietary manipulation of nitrogen retention and hence achieved live weight gain has not been easy. Manipulation by other techniques: choice of breed, sex, or hormonal treatment is quite common, but recognition of the sensitivity of live weight gains to changes in nitrogen retention are perhaps less well understood. Alderman (1980) has proposed a simple model which demonstrates this sensitivity and explains why increases in live weight gains of 15-20% can be achieved for the same energy intake and energy retention. It is important to recognise the substantial differences in maximum N retention which have been identified between UK and Continental breeds of cattle used for beef production, as these will affect their ability to respond to dietary manipulation designed to increase N retention.

TECHNICAL ASPECTS

A feature of work in the UK has been a continuing emphasis on rigorous testing and evaluation of techniques used to study protein/energy interactions. Rumen studies. Methods to measure outflow of microbial matter from the rumen have come under close scrutiny. The various microbial markers which have been used (diaminopimelic acid (DAPA), ^{35}S , ^{32}P , ^{15}N , RNA and amino-ethyl phosphonic acid (AEPA) may each give reproducible results but results from different markers do not always agree. The most comprehensive study of markers compared RNA, DAPA, ^{15}N , ^{35}S and amino acid 'profile' to identify microbial amino acid flow to the duodenum (Siddons, Beever et al., 1979) (Table 2). Other comparisons have been made between RNA, ^{35}S , DAPA and AEPA (Ling & Buttery, 1978) and between RNA, DAPA and ^{32}P (Smith et al., 1978).

The main conclusion from these comparisons is that no one microbial marker technique can be relied on at present to give a reliable absolute estimate of rumen microbial outflow.

Measurements of ATP yield in the rumen are often derived from measurements of volatile fatty acid (VFA) production. When experimental animals are continuously fed or where all forage rations are used VFA production can be estimated reliably (Sutton, 1980). But there is uncertainty over measurements of VFA production in animals fed twice daily and particularly when rations have a high proportion of concentrates. As many high-producing ruminants are fed in this way there are obvious problems in applying simple methodology to the more complex high production situation. Some theoretical advances have been made in studying VFA production in non-steady-state (Morant et al., 1979) and these are currently being tested in practice.

To advance knowledge it is important that measurements of different variables, obtained using various techniques, can be put together to give an improved understanding of the overall pattern of events. Some disconcerting inconsistencies can sometimes be seen (see Sutton, 1979) which show the need for great care in both application of techniques and interpretation of results.

NUTRIENT FLOW TO THE INTESTINES

Considerable progress has been made in automating measurement of flow of digesta into and out of the small intestine. For animals fitted with re-entrant cannulas automated apparatus for continuous collection, sampling and return of digesta have been built (Corse, 1974; Cammell, 1977). Very recently lightweight apparatus for frequent sampling of digesta from T-piece cannulas has been developed and used successfully on growing cattle under grazing conditions (Ulyatt *et al.*, 1980).

In all studies it is essential that sufficient animal replication and good experimental design is used so that experimental results can be used with confidence. From numerous studies of duodenal flow it is now possible to make recommendations on appropriate animal replication. Between animals the coefficient of variation in duodenal digesta flow is close to $\pm 10\%$. This means that, in two experiments out of three, to identify a significant difference ($P < 0.5$) in digesta flow between treatments of 20%, 15% and 10% would require respectively the use of a 4 x 4 Latin square, a 6 x 6 Latin square and a replicated 6 x 6 Latin square experimental design (Sutton & Oldham, 1977).

Some progress has been made in assessing the merits of various indigestible markers for digestion studies. Heavy metal, dual phase markers have been used successfully (MacRae & Evans, 1978; Beever *et al.*, 1978) and have many theoretical advantages (Faichney, 1975). Some problems have been found (Oldham, Sutton & Napper, 1980) and more attention in this area is likely.

NUTRIENT UPTAKE BY INDIVIDUAL ORGANS

Studies of nutrient uptake by the gut (Webster, 1974; Tagari & Bergman, 1978), liver (Bergman & Heitmann, 1978; Baird *et al.*, 1975) mammary gland (e.g. Bickerstaffe *et al.*, 1974), isolated hind-limb muscle (Bell *et al.*, 1974; Domanski *et al.*, 1974) and diaphragm (Coward & Buttery, 1979) have been reported. These studies have proved useful particularly in combination with use of radioisotopes (Linzell & Annison, 1975) for investigations of substrate oxidation, metabolic interconversions and net uptake (or output) of nutrients from particular organs and in relation to whole body metabolism. There has been relatively little recent progress in methodology for measurement of blood flow which remains the main source of error in the measurements.

COMPUTER MODELLING

The techniques of dynamic modelling are helping to identify those areas of nutrient interrelationships which have most impact on the net balance of metabolism within the rumen (Beever *et al.*, 1980) and it is likely that these studies will be extended to cover body metabolism with eventual integration into whole animal and system models.

PROTEIN-ENERGY INTERACTIONS IN THE RUMEN

Many of the developments in understanding P/E interactions in the rumen will be covered elsewhere in this Symposium. Some aspects can be selected from recent work which have been the focus of particular attention and which have considerable relevance to the high producing ruminant.

DILUTION RATE AND MICROBIAL GROWTH YIELD

Recent progress has been reviewed in detail by Harrison & McAllan (1980). When dilution rate (D, measured as fractional rate of outflow of PEG, Cr-EDTA or Ru

(phen), Cl_2 from the rumen) has been increased from very low ($< 0.05 \text{ h}^{-1}$) to moderate values ($0.1-0.15 \text{ h}^{-1}$) microbial growth yields (measured as microbial N per kg organic matter apparently digested in the rumen ($ADOM_{Ru}$)) have increased, presumably because maintenance requirements of the microbes play a proportionately smaller part in the overall energy demands for growth at the higher rates. Further increases in D (to level $> 0.15 \text{ h}^{-1}$) have much smaller effects on microbial growth yields. Consequently efforts to increase D may have greatest influence on microbial growth yield in situations where level of feeding and type of ration are conducive to low basal D rates - high concentrate rations for growing stock may be such an instance.

Where levels of feeding are high, and D is high - which is likely to be the case with dairy cows (D up to 0.25 h^{-1}) - it is less likely that efforts to increase microbial growth yield by changing D will be worthwhile. Consistent with this are recent observations that microbial growth yields in dairy cows are not very different from average values obtained with sheep (Table 3).

MICROBIAL GROWTH YIELD WITH DIETS BASED ON GRASS SILAGE

Until recently few studies had been concerned with grass silage rations even though this source of roughage fulfils 50% of forage needs for dairy cattle in the U.K. Microbial growth yields have been found to be relatively low with rations of this type (Table 4) which may be part of the explanation for the observed low nutritive value of crude protein in silage-barley diets (Castle, 1975).

A substantial part of the true protein in silage rations is very resistant to degradation in the rumen (Chamberlain, 1980). Addition of soybean meal to silage rations has improved microbial growth yields in cattle (Table 4) but not in sheep. The possibility that availability of pre-formed amino acids and peptides can limit growth yields cannot be ruled out although it does not provide the explanation in all cases. Sources of N other than NH_3 -N have been found to be preferred N-substrates for microbial N production under some circumstances (Salter *et al.*, 1979) and microbial growth yields have been increased *in vitro* by replacing urea-N by casein-N as principle N-substrate (Maeng *et al.*, 1976).

SOURCE OF CARBOHYDRATE FOR MICROBIAL GROWTH

Mixtures of starch and cellulose supported higher efficiencies of microbial growth than either substrate alone (Offer *et al.*, 1978). Similarly mixed roughage/concentrate rations have been found to maintain higher efficiencies than either high concentrate or high roughage rations (Kaufmann, 1980). For effective capture of 'degraded' N in the rumen it is necessary to match rate of release of N-substrates with rate of availability of energy from rumen fermentation. So it is the combination of source of dietary N and source of dietary carbohydrate which is important in determining net outflow of amino acids from the rumen (Oldham *et al.*, 1977).

FAT SUPPLEMENTATION AND MICROBIAL GROWTH YIELD

Fat supplements may gain increasing importance as vehicles to increase energy density of dairy concentrates and for manipulation of milk composition. There are indications that free and 'protected' lipids might influence microbial growth yields (Knight *et al.*, 1978). Increased growth yields with inclusion of lipid supplements in diets might be related to elimination of protozoa from the rumen with these diets. The value of maintaining or removing protozoa from the rumen has been discussed (Bird *et al.*, 1979), but the case for or against rumen protozoa as important agents determining efficiency of growth or milk production has not

yet been proved in the context of high rates of production with European diets.

PROTEIN-ENERGY INTERACTIONS IN THE BODY

1. Protein effects on partition of nutrients between tissue and milk

The hypothesis has been put forward that increasing protein supply to the tissues can increase energy deficit in cows already in negative energy balance early in lactation (Ørskov, Grubb & Kay, 1977). Part of the rationale behind this is that cows in negative energy balance (i.e. net tissue mobilisation) require extra protein (amino acids) to be absorbed from the intestine to match the available energy from mobilised tissue which, it is presumed, has a low protein content. But the suggestion goes beyond this to say that increased amino acid uptake from the intestine can stimulate further tissue mobilisation. Practical evidence for this is meagre but can be seen in some trials with ewes and cows in early lactation (Robinson et al., 1974; Robinson et al., 1979; Ørskov et al., 1981). In these experiments increasing protein content of some rations increased milk output at the expense of increased live weight loss early in lactation.

In contrast, a summary of evidence from other published trials (Danfaer et al., 1980) shows live weight loss decreasing with increasing protein input (Fig. 2).

Quite clearly, two very different mechanisms must operate to produce these contrasting results, although direct comparisons between experiments are made difficult by differences in basal rations, cow potential etc.

The likely explanation for situations in which increasing protein intake decreases live weight loss is that, under the prevailing conditions, increased protein input increases ration digestibility and/or food intake. The increased energy intake counterbalances energy release from tissue, thus reducing net tissue mobilisation (live weight loss).

The situation in which extra protein input increases tissue mobilisation is more difficult to explain. The key to the answer perhaps lies with the nature of rations with which the effect is associated. Krohn & Andersen (1978) varied protein intake in cows fed 12.8, 14.6 and 16.1 kg DM/day. DMI was increased by adding concentrate supplements to a fixed level of forage intake so that concentrate:forage ratio increased with increasing DMI. The results show that, within each level of DMI, increasing protein intake increased FCM yield, but that increases in DMI produced only very small increases in milk yields. Live weight loss increased as DMI decreased. Adjustment of FCM yields to zero live weight change produced a nearly linear response in FCM output to increase in CPI (see Oldham & Smith, 1980). Responses with the lowest level of DMI (and lowest concentrate:forage ratio) were exaggerated by enhanced live weight loss with increased protein intake whereas this did not happen at the highest level of DMI (highest concentrate:forage ratio). Similarly it has been shown (Ørskov et al., 1981) that protein supplements designed to increase amino acid supply to the intestines increased milk output at the expense of live weight loss with high forage rations (and relatively low intake) but not with high concentrate rations (and relatively higher intake).

The mechanisms involved are not clear. When amino acid supply to the tissues is low relative to the availability of energy-yielding nutrients, the metabolic choice facing the animal is either to dispose of surplus energy-yielding nutrients (catabolism + excretion) producing heat, or to store them, largely as fat. With high forage rations we can imagine a situation in which fat deposition is enhanced

when amino acid uptake is low, but increasing uptake of amino acids reduces the metabolic need for fat deposition with a resultant increase in net tissue 'mobilisation'.

With higher concentrate rations this mechanism may be over-ridden by enhancement of other control mechanisms related to diet type. Rumen propionate production is likely to increase with higher concentrate rations, with consequent effects on an increased tendency for lipogenesis in adipose tissue (Palmquist, 1976). Such a process is likely to be mediated by changes in hormonal status - in particular insulin and glucagon status might be implicated.

Even with relatively high concentrate rations increasing abomasal protein supply can have effects on lipid metabolism in cows - flux rates of acetate and palmitate through jugular venous blood have been increased with abomasal casein infusion (König *et al.*, 1980). The degree to which such effects can be translated into net contribution from adipose tissue into milk will depend on the degree of attenuation of the 'over-ride' mechanism referred to above.

It is likely that these effects on fat metabolism induced by increasing protein supply to the intestines may be mediated via changes in hormonal status. Growth hormone (GH) may be implicated as abomasal infusion of casein has increased blood GH in goats (Oldham, Hart & Bines, 1978) and feeding formaldehyde-treated proteins has increased blood GH in cows (Oldham, Hart & Bines, 1981). GH can have a lipolytic role (Jagannadha & Ramachandran, 1977) but it is interesting that one report (Gow *et al.*, 1979) reports no increase in blood GH in goats fed a high concentrate diet and abomasally supplemented with casein. One might speculate that the nature of the diet in this case was important in precluding any GH-mediated response.

The practical implication of this speculation on mechanisms involved in determining live weight-change response to variation in protein input is that live weight loss may increase with protein supplementation of high forage rations but is less likely to do so with high concentrate rations.

It has been suggested that amino acid supply to the liver - especially methionine supply - may have effects on lipoprotein synthesis with consequent effects on lipid flux through the liver and on adipose tissue mobilisation. The evidence for this is not great (Oldham, 1981) but this could be an additional point of interaction between protein input and lipid utilisation. In some circumstances very low protein diets may affect lipoprotein utilisation (Stead & Oldham, 1978) with consequent effects on milk fat output (Oldham *et al.*, 1979). It is worth noting that fishmeal inclusion in rations on-farm has not affected milk protein content but milk fat content was increased (Newman *et al.*, 1980).

2. Amino acids and glucose metabolism

Classical work by Bergman and his colleagues (see Bergmann & Heitmann, 1978) has shown that glutamic acid - glutamine and alanine are the main contributors of amino acid carbon to glucose carbon in fed mature sheep. A major question has been the extent to which the balance of metabolic events differs between the mature animal and the highly productive milk or meat producer.

By use of radioisotopes and compartmental modelling procedures Egan & MacRae (1979) have measured irreversible loss rates (IRL) and contribution of threonine C to glucose and bicarbonate C. Threonine was of interest as it may have roles both as a potentially limiting amino acid and as a glucose precursor. The results (Table 5) show that only 3-4% of threonine IRL contributed to glucose

C but up to 10% was oxidised to bicarbonate-C. Other work, reviewed by Lindsay (1976) supports this finding that, in lactating ruminants, oxidation of amino acid C is quantitatively more important than conversion to glucose C.

By using ^{14}C -urea dilution to measure blood urea IRL and relating this to glucose ($6\text{-}^3\text{H}$ -glucose) IRL, Bruckental *et al.*, (1980) have estimated possible net contribution of amino acid C to glucose C synthesis. With appropriate assumptions on partition of amino acid C catabolism between oxidation and glucose synthesis, and on the proportion of urea-N synthesis derived from amino acid catabolism it is clear that the proportion of glucose-C IRL which comes from amino acid C in the high-yielding cow is very small (< 5% of glucose IRL).

In early lactation when both amino acids and glucose are in short supply relative to demand, oxidation of glucose appears to be reduced (Bennink *et al.*, 1972; Bruckental *et al.*, 1980) and there is some indication that amino acid oxidation is also reduced (Egan & MacRae, 1979; Bruckental *et al.*, 1980). At the same time mobilisation of adipose tissue is stimulated with increased entry (IRL) of fatty acids into blood (König *et al.*, 1979) (Table 6). It seems reasonable to hypothesise that one result of increased fatty acid mobilisation is that mobilised fat acts as an alternative oxidisable substrate allowing reduced oxidation of amino acids and glucose in early lactation. There is evidence that, in general, glucose is less important as an oxidisable substrate in ruminant rather than non-ruminant muscle (Buttery, 1979).

Oxidation of amino acids

Oxidation can account for a substantial part of amino acid flux (Fig. 3). Essential amino acids are less extensively oxidised than non-essentials. Oxidation of branched-chain amino acids by muscle seems to be less extensive in ruminant than in non-ruminant muscle (Buttery, 1979). The reason for this may be related to the relatively high circulating levels of β -hydroxybutyrate in ruminants, which may reduce the rate of decarboxylation of branched-chain amino acids in ruminant muscle (see Lindsay & Buttery, 1980).

At high levels of protein intake conversion of excess absorbed N can incur an energy cost which may be big enough to result in negative performance response to increased protein intake. For example, Danfaer *et al.*, (1980) found milk yield decreased when protein intake increased beyond ~200 g CP/kg ration DM. The penalty paid by the animal for excessive protein intake is two-fold - first there is the additional energy cost of urea synthesis from excess protein N and second the increased energy output as urea is urine.

The cost of urea synthesis was estimated by Martin & Blaxter (1965) to be 13.4 kJ/g N converted from ammonia. Because not all urea synthesised is excreted the energy cost of urea excretion must make allowance for the proportion of urea synthesis which recycled to the gut. This proportion seems to be higher in productive ruminants than mature, non-productive ones (Table 7). For this reason the energy cost per unit urea excreted in urine (and milk in the case of lactating animals) is proportionately higher in the case of productive animals although the overall cost is still relatively low (~30 kJ/g urea N excreted in lactating cows). But taking this cost together with the energy value of urea itself (22.8 kJ/g N) into account, it is possible to explain for example, the reduced milk output with very high levels of protein feeding (Danfaer *et al.*, 1980) in terms of additional energy costs of surplus protein excretion. (In this example FCM yield fell by 1.4 kg/day when N intake increased by ~100 g/day. Cost of excreting this as urea N would be ~3 MJ for urea synthesis and ~2 MJ as energy content of excreted urea making a total additional net energy cost of ~5 MJ).

It is worth pointing out that the apparently greater proportionate recycling of urea-N in productive animals is a potential mechanism for N conservation if the urea recycles to the rumen and it is captured into microbial protein. Such a benefit has yet to be clearly demonstrated but it may have energetic connotations if microbial fermentation of ingested energy-yielding nutrient was limited by ammonia availability.

Influence of protein intake upon efficiency of utilisation of ME

Whilst protein in excess of normal requirements can be used as a source of energy, by deamination of amino acids and subsequent metabolism of the remaining carbon skeletons, disposal of the nitrogen as urea reduces the ME available to the animal as already mentioned. Tyrell, Moe & Flatt (1970) in their statistical analysis of 268 balance trials with lactating dairy cows found the cost of urea synthesis was nearly twice that reported by Martin & Blaxter (1965) in situations where the excess nitrogen was of the order of 100 g N/head/d. The effect however, was upon energy balance, and not upon the efficiency of ME utilisation. Moe, Tyrell & Flatt (1970) in a companion paper, then proceeded to correct ME intakes as measured by 50 kJ for each g N calculated to be in excess of requirement. Later work by these authors confirmed an effect of q upon k_1 , the efficiency of ME utilisation for milk, as did Van Es (1978) but no effect of protein was identified, presumably because of this correction.

Schneider, Fritz, Reichl & Menke (1979) however were able to show an effect of protein/energy ratio expressed as g CP/MJ ME upon k_1 , both in their own trials with dairy cows, and also in the data of Schiemann *et al.*, (1970, 1972). They proposed an equation:

$$k_1 = 0.119 \text{ M/D} - 0.00502 \text{ M/D}^2 - 0.0082 \text{ CP/ME or } 2.19q - 1.70q^2 - 0.0082 \text{ CP/ME.}$$

This predicts a shift in value of k_1 from 0.60 to 0.58 as the crude protein concentration of a diet of M/D 11 MJ/kg is increased from 140 to 160 g/kg DM. It appears that Schneider *et al.*, did not correct ME intakes for excess N intake, so that the energy cost of urea synthesis and excretion is being counted as part of heat production of milk synthesis.

Blaxter & Boyne (1978) in their fuller analysis of calorimetric data for growing sheep and cattle, were able to show a small effect of protein upon both k_p and k_g in addition to the larger effect of q . In the case of k_m , increased protein (from 100 to 200 g CP/kg OM) reduced efficiency at $q = 0.6$ from 0.72 to 0.70. In the case of k_g for similar changes, the change was from 0.45 to 0.52, a large and more positive effect which is difficult to explain.

The controversy over relative efficiencies of VFA for fattening has recently come under critical scrutiny by MacRae & Lobley (1980) with a suggestion that protein/energy interrelationships may play a part in explaining the apparently contradictory results from different investigations. The hypothesis put forward was that for efficient utilisation of acetate sufficient reducing equivalents (NADPH) must be supplied and that in some experiments (high efficiency of utilisation of acetate) glucogenic amino acid supply was sufficient to meet this demand whereas in others (low efficiency of utilisation) it was not.

In support of this Ribeiro *et al.*, (1980) have measured k_g and duodenal amino acid flow in sheep fed spring or autumn harvested grass and have found both higher k_g (as expected) and higher duodenal amino acid flow (per MJ ME intake) in sheep fed spring-harvested grass.

This hypothesis is still at an early stage of testing but may be a considerable advance in rationalising much of the earlier work on efficiencies of VFA utilisation and in explaining the large differences in k_g which have been found in mixed forage and cereal diets of apparently similar ME content (Thomson, 1978).

Effects of excess ammonia absorption on glucose metabolism

There have been indications that excessive absorption of ammonia from the gut may impair glucose metabolism (Leonard, BATTERY & Lewis, 1977). The reasons for this are still not known. One possibility is that depletion of 2-oxoglutarate by the action of glutamate dehydrogenase leads to derangements in the tricarboxylic acid cycle. Another consequence would be disturbance of the redox state of pyridine nucleotides. Alternatively increased blood ammonia concentration may inhibit transport of K into cells which would disrupt Na/K-linked active transport processes.

Pattern of feeding seems to be important in determining the nature of response which has made it a difficult problem to study - effects on glucose metabolism seem to be greater in animals fed once or twice per day, and less in animals frequently fed. As studies of glucose kinetics generally rely on maintenance of steady-state conditions by feeding there is an obvious conflict in establishing both the right nutritional regimen and the right theoretical conditions for measurements.

The possibility remains that excessive ammonia uptake from the gut may influence production via effects on glucose metabolism.

Energy costs associated with protein synthesis

In relation to metabolic body weight ($\text{kg}^{0.75}$) rates of whole body protein synthesis seem to be relatively constant between species at $\sim 12\text{--}18 \text{ g/d/kg}^{0.75}$ in mature animals (Reeds & Lobley, 1980). Values for growing animals ranged from $17\text{--}23 \text{ g/d/kg}^{0.75}$ and for lactating ruminants from $14\text{--}22 \text{ g/d/kg}^{0.75}$ (Table 8).

Between species comparisons have revealed a close linear relationship between protein synthesis and heat production (Webster, 1980). It has been argued that this close association between protein synthesis and heat production indicates that protein synthesis and those aspects of metabolism associated with it may account for about 50% of heat production (Webster *et al.*, 1978). This is not a measure of the energy cost of protein synthesis - the true cost of protein synthesis would generally be accepted as $\sim 4.5 \text{ kg/g}$ protein synthesised, or about 15% of heat production (Reeds & Lobley, 1980; Reeds *et al.*, 1980).

The implication is, rather, that other energetically costly processes such as pumping of Na and K correlate closely with protein synthesis. The statistical correlation between heat production and protein synthesis might, however, suggest that techniques to manipulate the rate of protein accretion per unit protein synthesised may have consequences on the energetic efficiency of growth. For example, rats treated with trenbolone acetate increased rate of protein accretion but decreased protein synthesis rate because protein degradation rate was reduced even more than synthesis (Vernon & BATTERY, 1976).

It has yet to be established that similar mechanisms work in determining growth responses of ruminants implanted with anabolic agents. But if it becomes possible to manipulate relative rates of protein accretion and synthesis there may be important implications for manipulating the energetic efficiency of growth.

MANIPULATION OF N METABOLISM BY CHEMICAL AGENTS

Nutrient utilisation in a defined physiological state can be influenced by means other than manipulation of diets. Choice of sex - bull, steer or heifer - has effects upon N metabolism which can now be implemented at will by the use of anabolic steroids. Commercial products are in widespread and successful use due to the 10-15% increase in weight gain and reduced FCR achieved. Concern over residue problems in meat for human consumption have arisen and legislative proposals may limit their use in future. This will no doubt give impetus to the search for effective and financially practical alternatives.

Other types of growth promoter have been found, such as Monensin Sodium - originally a coccidiostat for non-ruminants. The mode of action is different from that of anabolic steroids, but improvements in FCR, though not necessarily weight gain, are achieved.

1. Monensin

Monensin sodium decreases dry matter consumption with very little effect on live weight gain (Raun *et al.*, 1976; Byers, 1980) which implies changes in efficiency of utilisation of nutrients. Although monensin induces a pronounced reduction in the ratio of acetic:propionic acid concentrations in the rumen, presumably due to effects upon rumen microbes, the magnitude of the change is too small to account for the overall increase in utilisation of food. (This presumes that k_p for propionate is higher than for acetate, a presumption which may be false for adequate protein rations; see MacRae & Lobley, 1980). Byers (1980) has indicated that monensin increases the apparent efficiency of energy use for maintenance (by ~6%) but has no effect on apparent efficiency of energy use for growth. Monensin facilitates Na flux at the cellular level, possibly decreasing energy requirements for maintenance of cellular osmotic gradients (Degani & Elgavish, 1978; Saini *et al.*, 1979) and this might be expected to reduce maintenance energy requirements.

At the same time, monensin can reduce food protein degradation within the rumen (Van Soest & Demeyer, 1977; Chalupa *et al.*, 1980; Poos, Hanson & Klopfenstein, 1979) which might, in some circumstances increase amino acid supply to, and uptake from the intestines. The possibility therefore exists for interactions between protein and energy metabolism at tissue level as a result of monensin treatment. There is some evidence that these interactions (if they exist) result in alteration in body composition (reduced fat:protein ratio) in cattle treated with monensin at limited but not at *ad libitum* intakes (Byers, 1980).

2. Anabolic agents

The action of anabolic agents in current commercial use is to increase the efficiency of meat production and muscle protein deposition, (N retention) (Heitzmann, 1978, 1979). The mechanism of action is not fully understood. Androgens and oestrogens may act via different mechanisms - androgens probably acting directly at the muscle cell and oestrogens acting indirectly through growth hormone (GH) and insulin. But it is possible that both androgens and oestrogens have an independent action through the control of thyroid hormone status.

Urea production is also reduced by anabolic treatment of cattle (Donaldson, 1977) but the overall consequence of this on N economy - and any energetic overtones - have yet to be evaluated.

The effects of anabolic agents on rates of gain and feed conversion ratio might suggest alterations in energetic efficiency of growth but direct evidence is

lacking. If allowance is made for the changes in proportion of protein and fat in the gains, this effect is likely to be small. Alderman (1980) has calculated that an increase in protein gain of 25 g/d will increase live weight gains by 14% for the same net energy retention. Reference has already been made (p.10) to the effects of trenbolone acetate on protein synthesis and degradation in rats which, if also applicable to cattle, might have consequences on energetic efficiency of growth.

3. Growth hormone

Despite its name this hormone has attracted more attention with regard to its influence on milk production than it has on growth. Blood concentrations of growth hormone are higher in cows at high, compared with low milk yields (Hart *et al.*, 1978). The reverse is true for insulin. Injection of GH into cows in mid-lactation has been found to increase milk yield and N excretion in milk with a concomitant reduction in urinary N output (Bines *et al.*, 1980). GH injection also reduces irreversible loss rate of urea from jugular venous blood in cows both early and late in lactation but the effect of GH injection on milk yield has not been observed in early lactation (Hart *et al.*, 1980). There appear to be no effects of GH injection on irreversible loss of glucose from venous blood which has led to the speculation that GH exerts its effect on milk yield by inhibiting uptake of glucose by peripheral tissues thus increasing glucose availability at the mammary gland (Hart *et al.*, 1980). It is not clear at this stage if the effects of GH on urea metabolism are associated with or independent from glucose-related phenomena, but an association seems likely.

Control of nutrient utilisation

These few observations on non-dietary means of manipulating energy and protein status point to a growing emphasis on work designed to outline the major control processes governing utilisation of absorbed nutrients ('intermediary metabolism'). Forbes (1981) gives an up-to-date assessment of the state of knowledge in this complex area. Many problems of methodology and interpretation must be resolved before real progress can be made. But it seems likely that the first moves, which have already been made, towards a real understanding of the major control processes signal a real advance in the overall approach to the description of nutrient use.

Practical implications

A great deal of the recent UK research effort on understanding protein/energy interrelationships in ruminants has been pertinent to the development of a new system for assessing protein requirements (ARC, 1980). And it is likely that much of the effort in the future will be geared to refinement of the present proposals into workable practical guidelines.

The ARC (1980) Ruminant protein requirements system has much in common with other systems proposed elsewhere in Europe and around the world. In all of the systems it is essential to know the efficiencies with which amino acids supplied to the intestines are, first, absorbed and, then, utilised. The efficiency of utilisation of absorbed amino acid can be considered as the net efficiency of intermediary metabolism of amino acids. So there is a clear role for using knowledge of protein/energy interrelationships in intermediary metabolism of ruminants to describe the potential variation of this important factor in practice. Very few measurements have been made of this efficiency factor - Table 9 probably contains most of the values available. But a simple analysis of the sensitivity of calculations of protein needs, using the new system, to variation in the efficiency of transfer of duodenal amino acids into product quickly shows how vital

to the success of the new system(s) will be improved knowledge of the factors affecting efficiency of absorption of amino acids and their utilisation. As an example Fig. 4(a & b) shows the results of some calculations for a 550 kg cow, yielding 35 kg milk/day and consuming 225 MJ ME/day. As the combined efficiency factor falls calculated duodenal need rises and all of the apparent increase has to be supplied as 'undegraded' food protein (Fig. 4 a) because it is assumed that microbial protein supply is fixed by ME intake (ARC, 1980). The consequence is that the 'degradability' of ration protein required to meet calculated duodenal needs varies substantially with the efficient factor chosen. An alternative approach is to calculate the required ration crude protein content for a ration of protein 'degradability' of, say 0.65 when the efficiency factor varies (Fig. 4 b). This example shows very dramatically how sensitive the calculations of protein needs can be to relatively small variations in the efficiency factor. The value (0.525) adopted by ARC (1980) lies well within the region of high sensitivity.

It will obviously be as important in the future to aim for appropriate quantification of the 'Intermediary metabolism' of absorbed amino acids as it has been, and will continue to be, to quantify processes within the rumen.

CONCLUSION

UK research on protein/energy interrelationships in intermediary metabolism of ruminants has been on a wide front. The increased effort on 'body metabolism' in recent years indicates a change in emphasis from almost total commitment to work on events associated with digestion of nutrients to greater effort in understanding factors which influence nutrient utilisation. By combining information on digestion with that on nutrient utilisation and linking these with measurements of animal performance we hope to get a more complete understanding of the mechanisms which link food input to productive output. The ultimate aim is not merely to be able to explain how and why animals perform as they do on particular rations, but to allow greater precision in manipulating animal performance by tailoring nutrient inputs to gain maximum benefit in defined production systems.

Progress has been linked very closely with the development and improvement of appropriate experimental techniques. The stage is now set for substantial advancements in understanding the complex mechanisms which influence quantitative metabolism of absorbed nutrients. Our present picture of ruminant intermediary metabolism is one of a selection of observations on diverse aspects of the subject which cannot readily be drawn together into a coherent whole. We can expect more emphasis on quantification of metabolic processes in high-producing (rather than non-productive) ruminants in the future and widespread application of computer modelling techniques to test hypotheses and integrate information on dynamic aspects of the ruminant metabolic system.

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TABLE 1 Measures of the response of cows to variation in crude protein consumption. In all cases responses (in dry matter intake (DMI) and fat-corrected milk yield (FCM)) are from experiments in which ration CP content was varied and cows had ad libitum access either to silage or complete mixed ration

Source	Ration type	kg DMI/ CP%	Δ FCM kg/ d	Δ DMI/kg/ d	FCM/ Δ DMI	Basal ration CP%
Laird et al. (1979)	Grass silage + concentrates	0.84	1.5	1.42	1.06	13.6
Castle et al. (1979)	" " (long chop) + concs.	0.09	0.4	0.52	0.77	14.6
	" " (medium chop) + concs.	0.16	0.7	0.66	1.06	14.5
	" " (short chop) + concs.	0.27	1.1	0.78	1.41	14.4
Gordon (1979)	Grass silage + concs.	0.08	3.1	0.47	6.6	12.5
Gordon (1980)	" " (unwilted) + concs.	0.09	0.7	0.3	2.33	16.7
	" " (wilted) + concs.	-0.05	2.2	0.6	3.67	17.1
	" " (wilted, low D) + concs.	0.19	1.1	0.8	1.38	13.6
Thomas et al. (1980)	" " (no treatment) + maize or maize + soya	0.04	0.8	0.3	2.67	16.5
	" " (+ formic acid + formaldehyde) + maize or maize + soya	0.19	0.9	1.2	0.75	16.8
Edwards et al. (1980)	Alfalfa hay + concentrates	0.13	2.85	0.4	7.13	13.0
Claypool et al. (1980)		0.15	3.0	1.0	3.0	12.7
Murdoch & Hodgson (1979)	Maize silage, alfalfa hay + concs.	0.52	2.3	1.6	1.44	14.4
Netemeyer et al. (1980)	" " " " " "	0.83	4.15	2.4	1.73	13.7
Clay & Satter (1979)	" " " " " "	0.5	5.3	3.0	1.77	10.5
Kwan et al. (1977)	" " " " " "	0.35	3.3	1.7	1.94	11.7
Poos et al. (1979)	" " " " " " (soya)	0.56	2.7	1.9	1.42	13.6
	" " " " " " (urea)	0.26	3.6	0.9	4.0	13.6
	" " " " " " (heifers)	0.17	0.3	0.5	0.6	12.4
Roffler et al. (1979)	" " " " " " (cows)	0.36	5.0	1.65	3.03	12.1
Majdoub et al. (1978)	Sorghum silage + concs. (low solubility protein)	1.35	3.5	4.18	0.84	12.2
	" " (high solubility protein)	-0.24	2.0	-0.55	-3.6	13.0
Chandler et al. (1976)	Maize silage, alfalfa hay + concs.	0.2	1.3	0.6	2.17	12.5

TABLE 2 Flow of amino acids of microbial origin to the duodenum of sheep estimated by different methods.

Values are given as g/d (+ standard error for 6 sheep) and, in parentheses, flows relative to ^{35}S -methionine as 100%. (From Siddons, Beever et al, 1979).

Technique	Diet			
	Grass silage		Dried Grass	
	g/d	% of ^{35}S value	g/d	% of ^{35}S value
Amino acid [*] profile	15.9+3.11	49	14.4+2.52	50
^{35}S -methionine	32.5+2.36	100	28.8+2.37	100
^{15}N	35.4+1.58	109	38.4+1.82	133
DAPA	60.4+6.07	186	65.8+5.96	228
RNA	73.5+5.88	226	66.2+4.88	230

^{*} See Evans et al, (1975)

TABLE 3 Rumen microbial growth yields in lactating cows

Ration	Level of feeding (kg DM/d)	Microbial N/kg ADOM _{Ru}	
		DAPA	RNA
60% Barley Concentrates, 40% hay ¹	12.7	33.9	37.1
60% Maize Concentrates, 40% hay ¹	12.4	21.9	27.9
90% Barley Concentrates, 10% hay ¹	12.1	30.7	35.8
90% Maize Concentrates, 10% hay ¹	11.9	13.2	19.7
60% Concentrates, 40% hay (13% CP) ²	8.2	29.2	57.5
60% Concentrates, 40% hay (19% CP) ²	8.2	30.3	42.0
60% Concentrates, 40% hay (24.3% CP) ²	8.2	28.5	55.8
70% Concentrates, 30% hay (13% CP) ²	12.9	29.0	38.2
70% Concentrates, 30% hay (19% CP) ²	12.9	27.5	42.2
70% Concentrates, 30% hay (24.3% CP) ²	12.9	29.7	51.4
Mean		27.4	40.8
Mean from non-lactating ruminants ³		32	

1. From Oldham et al (1979)

2. From Tamminga (1978) and Tamminga et al, (1979)

3. From Broster & Oldham (1977) - values contributing to mean were from studies using a variety of microbial markers.

TABLE 4 Rumen microbial growth yields for silage-based diets. Growth yields are expressed as g microbial N/kg organic matter apparently digested in the rumen (ADOM_{Ru})

Source	Basal Diet	Treatment	Microbial N/ADOM _{Ru}	Animal
Siddons et al, 1979	Perennial	Untreated	21.6	Sheep
	Ryegrass	+ formic acid + formaldehyde (F/F)	27.3	
	Silage	+ F/F + urea	23.3	
		+ F/F + urea + soya	18.0	
Thomas et al, 1980	Grass silage, wilted	Spring cut	22.7	Sheep
	treated with	Spring cut + barley	25.8	
	formic acid	Early Autumn cut	10.9	
		Late Autumn cut	16.5	
Beever et al, 1977	S24 Ryegrass silage	No treatment	33.4	Sheep
		+ formaldehyde	13.2	
		+ formaldehyde + dried	15.4	
Brett et al, 1979	Wilted silage	No treatment	27.3	Cattle
		+ barley + dairy cake	27.7	
		+ barley + dairy cake + soya	34.8	
Overend & Armstrong, 1980 (Quoted by Armstrong, 1980)	Wilted silage	No treatment	25.3	Cattle
		+ formic acid + formaldehyde (F/F)	25.2	
		+ F/F + soya	31.0	
Mean	Grass silage	No treatment	23.5	

TABLE 5 Quantitative metabolism of threonine-C in sheep
(Data of Egan & MacRae, 1979)

Physiological state	Threonine irreversible loss (g C/day)	Percentage of irreversible loss contributed to:	
		glucose C	CO ₂ -C
Mature	3.1	3	10-12
105 d Pregnant	4.9	4	8
140 d Pregnant	5.7	4	8
14 d Lactation	5.2	4	7

TABLE 6 Change in metabolite entry (irreversible loss) with stage of lactation in Friesian cows offered a ration containing 170 g CP/kg DM and comprising 3 kg hay + 9 kg concentrates (week 2) and 4 kg hay + 12 kg concentrates (weeks 4 & 9)*

Weeks after calving	2	4	9
Milk yield (kg/day)	27.1	30.8	27.9
Live weight (kg)	560	534	510
Irreversible loss (mM/day/kg body weight)			
Urea	9.9	9.9	16.2
Glucose	23	30	34
Palmitate	5.0	2.9	2.3
Acetate	95	138	128

* Data from König *et al.* (1979) and Bruckental *et al.* (1980).

TABLE 7 The proportion of urea irreversible loss which is not excreted in urine (or milk) in ruminants in different physiological states

Ration CP (g/kg)	Animal	% not excreted	Source
95-115	Mature sheep	28-52	Ford & Milligan, 1970
<50	Mature sheep	62-92	
>100	Mature sheep	23-56	
151	Mature sheep	32	Cocimano & Leng, 1967
151	Pregnant sheep	43	
60	Mature sheep	56	Allen & Miller, 1976
82		44	
100		37	
116		17	
60		92	
82	Growing lambs	80	
100		68	
116		61	
170		72	
	Lactating cows (First month of lactation)		Bruckental <u>et al</u> , 1978
170	Lactating cows (Second month of lactation)	55	
80-150	Lactating cows	59-93	Conrad, 1972

TABLE 8 Whole body protein synthesis ($\text{g}/\text{W}^{0.75}/\text{d}$) in mature, growing and lactating animals calculated from flux of leucine and adjusted for losses through oxidation

		Protein synthesis ($\text{g}/\text{W}^{0.75}/\text{d}$)
Adult:	Rabbit ¹	15.0
	Man ¹	12.5
	Sheep ¹	15.7
	Cattle A ²	15.1
	B ³	17.9
	C ⁴	15.3
	Ewe ⁷	11.5
Growing:	Rat ¹	16.7
	Pig ¹	18.9
	Cattle ²	22.9
Lactating:	Cow A ⁵	22.1
	B ⁶	14.2
	Ewe ⁷	15.8

1. Reeds & Lobley (1980)
2. Lobley *et al.*, (1980)
3. J.D. Oldham & G.E. Lobley (1980), unpublished results
4. Reeds *et al.*, (1980)
5. Oldham, Lobley *et al.*, (1980)
6. Black (1968)
7. Calculated from data of R.W. Smith & D.T.W. Bryant (unpublished) for tyrosine flux in dry or lactating ewes. Values were corrected for the difference between synthesis estimated from leucine or tyrosine flux (Oldham *et al.*, 1980).

TABLE 9 Efficiency of transfer of amino acids into product. Two efficiencies are recorded - the net conversion into productive N of amino acids entering the intestines, or the efficiency of utilisation of absorbed amino acids for productive N formation (efficiency of protein utilisation, EPU)

(a) Lactating ruminants

Source	Milk yield kg/day	Weeks after calving	Net conversion of duodenal amino acids to product				EPU**	Diet	Technique
			A		B				
			A	B	A	B			
Oldham, Sutton & McAllan, 1979	15	>14	0.42	0.38	0.6 ⁺	0.54 ⁺	40% hay + barley concentrates	Duodenal flow and feeding trial	
	16	"	0.47	0.42	0.67 ⁺	0.60 ⁺	40% hay + maize concentrates		
	19	"	0.49	0.45	0.7 ⁺	0.64 ⁺	10% hay + barley concentrates		
	16	"	0.56	0.51	0.8 ⁺	0.73 ⁺	10% hay + maize concentrates		
Bruckental, Oldham & Sutton, 1980	27	2	-	-	0.76	0.71	25% hay + 75% barley concentr.	Amino acid oxidation (urea production)	
	31	4	-	-	0.77	0.72			
	28	9	-	-	0.66	0.61			
	<15	>20	-	-	-	0.84	Alfalfa hay plus concentrates	14C amino acid oxidation	
Calculated by Oldham (1979) from various reports by Black & Colleagues Ørskov et al. 1977	"	"	-	-	-	Leucine 0.64			
	"	"	-	-	-	Phenylalanine 0.64			
	"	"	-	-	-	Threonine 0.64			
	"	"	-	-	-	Isoleucine 0.61			
	17-20	2-9	-	0.57	-	0.82 ⁺	Mixed diet (-65% concentrates)	Incremental response to abomasal protein	
Robinson et al. 1979 (Eves)		1-4	-	0.51	-	0.73 ⁺	50:50 Hay:rolled barley concentr.	Incremental response to abomasal protein	

(b) Growing ruminants

Source	Animal	EPU**		Diet	Technique
		A	B		
Corbett & Perez, 1979	Lamb (15-20 kg)	0.30 (0.43) 0.27 (0.45)	0.21 (0.31)* 0.19 (0.27)	Grazed Lucerne Grazed Phalaris aquatica Concentrates + dried grass	Abomasal flow and feeding trial Intestinal absorption and N retention
Black et al. (quoted in ARC 1980)	Steer (~100 kg)	0.75	0.57	Grass silage Grass silage (formaldehyde treated)	Intestinal absorption and N retention
Thomson & Beaver, 1980	Steers (~130 kg)	0.39 0.42	0.25 0.27		

A. Production N = milk N + N content of live weight change + endogenous urinary N

B. Production N = milk N + N content of live weight change

+ Calculated from net conversion assuming 0.7 of duodenal amino acids are absorbed from the intestines.

** Efficiency of Protein Utilisation

* Values in parenthesis are for efficiency of utilisation of absorbed N excluding wool N which was assumed by the authors to be produced with an efficiency of 0.12.

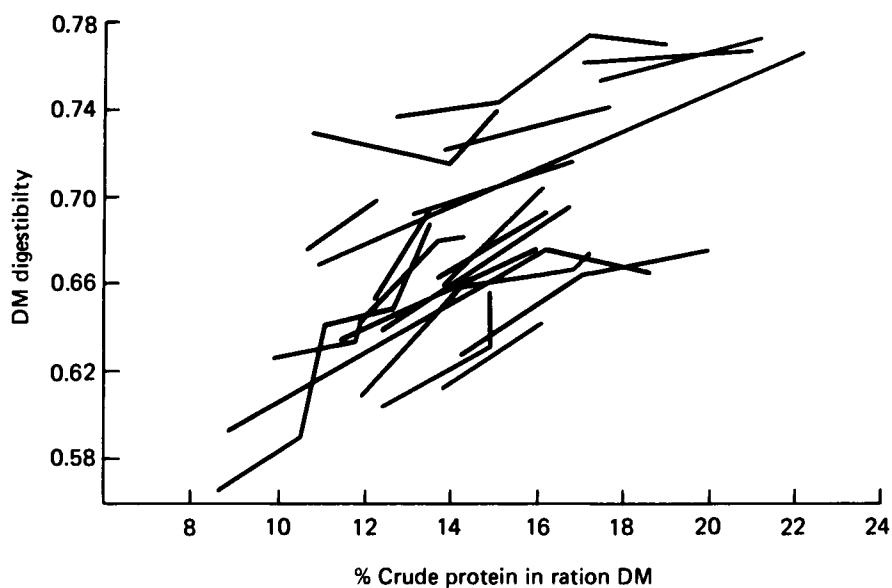


Figure 1. Relationship between ration crude protein content (% CP in DM) and whole-ration DM digestibility for measurements made using cows at production levels of intake (see Oldham & Smith, 1981 for sources of data. Lines link results from individual experiments).

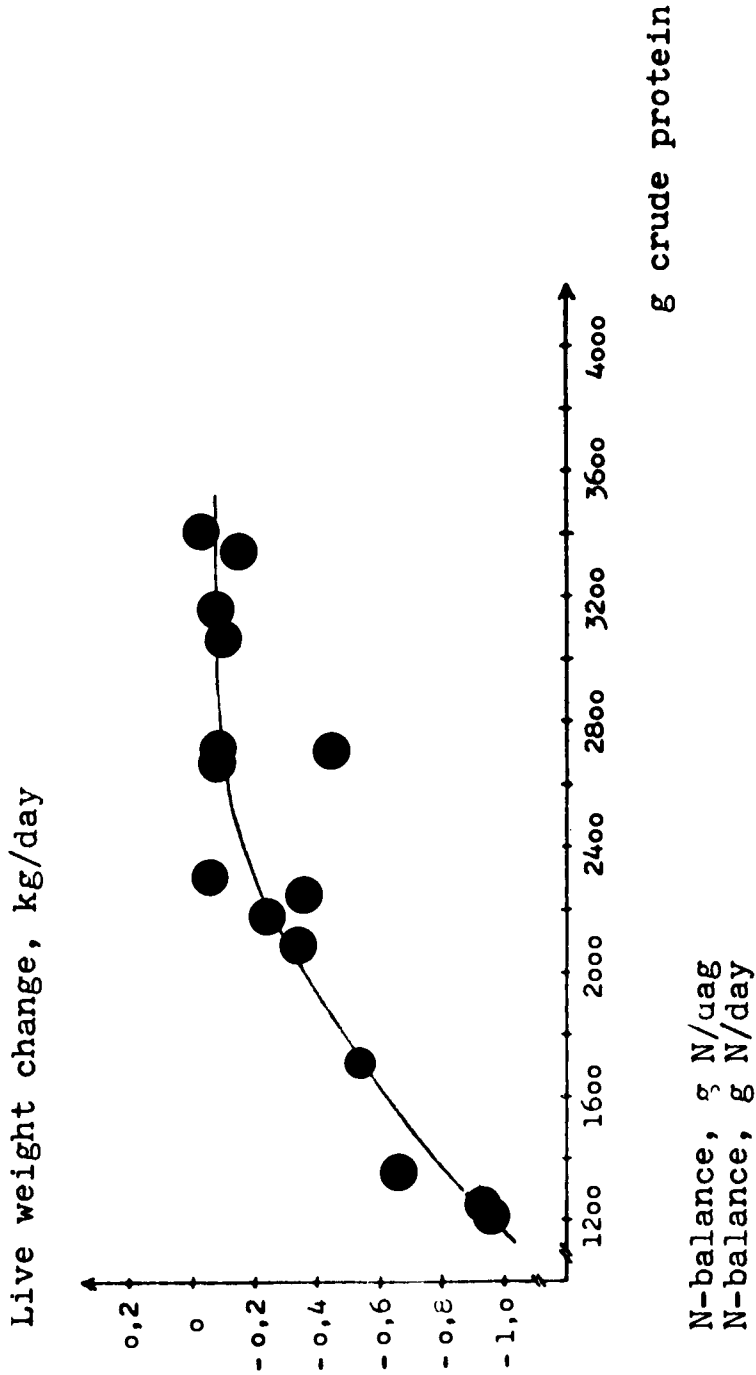
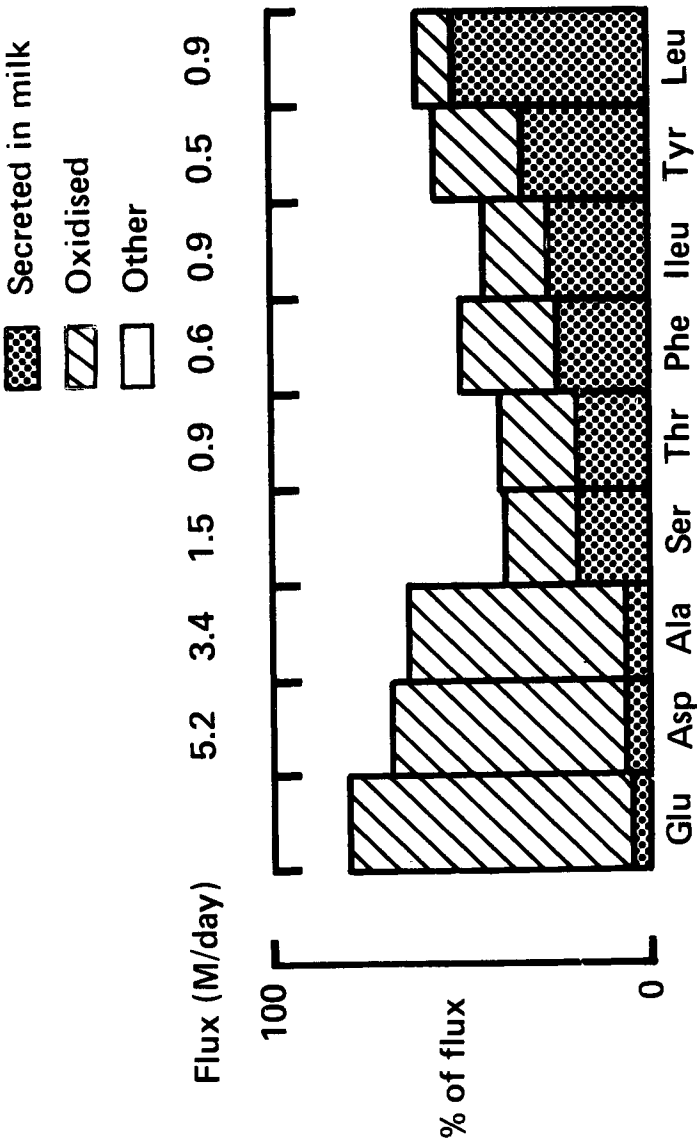
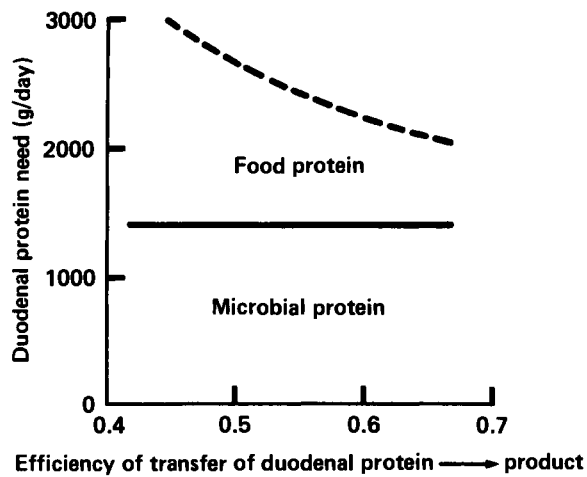


Figure 2. Effect of increasing crude protein intake on liveweight change in early lactation (see Danfaer et al, 1980).

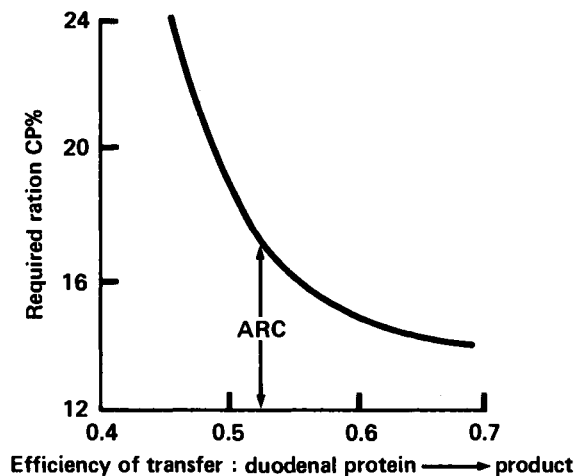


Adapted from Black and co-workers

Figure 3. The quantitative metabolism of intravenously injected ¹⁴C-labelled amino acids in dairy cows. Data have been calculated from results of Black and colleagues (e.g. Black, 1968). (See Oldham, 1979 for details).



(a)



(b)

Figure 4 (a & b). The influence of the assumed value for efficiency of transfer of duodenal amino acid supply into product (milk, and/or tissue plus maintenance) on a) calculated requirements for protein supply to the duodenum and b) calculated requirements for ration crude protein content for a ration containing proteins of average rumen degradability 0.65. All calculations are for a 550 kg cow, consuming 225 MJ ME, losing 0.5 kg bodyweight and yielding 35 kg milk per day. The efficiency value (0.525) adopted by the Agricultural Research Council (ARC) Nutrient Requirements Working Party is shown.

L'Importance des Relations Proteines-Energie dans la Pratique de l'Alimentation du Betail Laitier

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Les effets des niveaux d'apports énergétiques et azotés sur la production laitière ont fait l'objet de nombreux travaux qui ont été rapportés dans plusieurs revues (AURIOL et JARRIGE, 1962; REID et al., 1966; BROSTER, 1972). La réponse aux apports de matières azotées digestibles est beaucoup plus variable que pour les apports énergétiques. Elle varie non seulement en fonction du niveau des apports azotés relativement aux besoins mais aussi en fonction de la nature des sources azotées (BROSTER, 1972); ainsi qu'en fonction du niveau des apports énergétiques et du niveau de satisfaction des besoins énergétiques des vaches laitières (JOURNET et VERITE, 1977).

La variabilité des réponses de la production laitière aux apports azotés exprimée en matière azotée digestible et son interférence avec le niveau des apports énergétiques est due à plusieurs causes :

1) les matières azotées digestibles ne permettent pas d'estimer de façon précise la fourniture d'acides aminés pour la satisfaction des besoins, ceux de la mamelle en particulier. Cette fourniture dépend en effet de la fraction des protéines des aliments qui ne sont pas dégradées dans le rumen et des protéines microbiennes synthétisés dans le rumen.

Les nouveaux systèmes de prévision des apports et des besoins azotés se sont proposés de quantifier ces deux fractions (cf. revues de WHITLOW et SATTER, 1979; VERITE et al., 1979), ce qui nécessite en particulier de connaître le coefficient de dégradabilité (ou de fermentescibilité) des matières azotées des aliments dans le rumen et le rendement de la synthèse des protéines microbiennes (VERITE et al., 1979). Celui-ci dépend de la quantité de matière organique digestible ingérée, ce qui lie la fourniture d'acides aminés à l'apport énergétique;

2) l'apport azoté peut agir aussi sur la fourniture d'énergie à l'animal par ses effets sur la digestion dans le rumen ou sur le métabolisme en général. En effet, en cas d'apport insuffisant d'N fermentescible aux microorganismes, il peut en résulter une diminution de l'activité microbienne et par voie de conséquence une diminution de la digestibilité et de la valeur énergétique de la ration (JOURNET et REMOND, 1980). Il peut aussi en résulter une diminution de l'indigestibilité de la ration si l'alimentation est ad libitum. Et en cas de mauvaise nutrition azotée des animaux, par suite d'une fourniture insuffisante d'acides aminés, l'appétit (ou capacité d'ingestion) des animaux peut se trouver réduite, et consécutivement l'ingestion volontaire d'énergie (JOURNET et REMOND, 1976).

3) L'effet de l'apport d'azote aminé sur la production laitière peut aussi dépendre de l'état de nutrition énergétique (JOURNET et VERITE, 1977). Les acides aminés peuvent en effet servir comme sources d'acides aminés indispensables pour les synthèses de protéines du lait, et comme sources de chaînes carbonées pour la fourniture d'énergie et de glucose à la mamelle. L'efficacité d'utilisation de l'énergie pour la production de lait semble aussi dépendre de l'équilibre

entre les apports azotés, les apports énergétiques et la nature des sources d'énergie (fourrage ou aliments concentrés) (JOURNET et al., 1976).

Nous rapporterons les résultats principaux réalisés au Laboratoire de la production laitière de l'INRA de Theix concernant l'effet des apports azotés sur les performances des vaches laitières, en distinguant l'effet de l'apport d'azote fermentescible de celui de l'apport d'azote aminé (exprimé en quantité de protéines digestibles dans l'intestin grêle : PDI) selon le système proposé en France. Ces effets principalement en début de lactation seront étudiés à différents niveaux d'apport énergétique ou à différents niveaux d'apport de complément énergétique.

I. EFFET DE L'APPORT D'N FERMENTESCIBLE ET INTERACTION AVEC L'APPORT ENERGETIQUE

1) L'N facteur limitant de l'activité des microorganismes du rumen :

Les microorganismes du rumen d'une part dégradent une partie plus ou moins grande des matières azotées jusqu'au stade ammoniacal et d'autre part synthétisent leurs propres protéines microbiennes en utilisant 1) l'énergie issue de la fermentation de la matière organique et 2) l'azote disponible, sous forme ammoniacale principalement. Si la formation d'N ammoniacal dans le rumen est insuffisante, il peut en résulter une diminution de l'activité microbienne et en conséquence de la synthèse de protéines microbiennes. In vitro, il semble que la teneur en N ammoniacal ne devrait pas être inférieure à 5 mg/100 ml (SATTER et SLYTER, 1974). Les études in vivo situent cette teneur minimale entre 5 et 20 mg/100 ml selon les conditions d'alimentation et la composition des rations (ALLEN et MILLER, 1976).

Mais l'apport insuffisant d'N fermentescible (source d'N ammoniacal) peut également diminuer l'activité fermentaire et en particulier les activités cellulolytiques et amylolytiques des microorganismes du rumen comme l'indique le schéma 1. Il en résultera : 1) d'une part, une diminution de la digestion des constituants pariétaux des fourrages et constituants amylacés des céréales et donc de la digestibilité de la matière organique de la ration et de sa valeur énergétique;

2) d'autre part, une digestion plus lente des fourrages d'où un temps de séjour plus important dans le rumen et par voie de conséquence, une diminution des quantités ingérées. Ces deux effets cumulés sur les quantités ingérées et la valeur énergétique auront pour résultat de réduire les apports énergétiques en même temps que les apports azotés d'origine microbienne.

2) Quantification des besoins en N fermentescible des microorganismes du rumen dans le système PDI :

Il a été admis dans le système PDI (VERITE et al., 1979) que la quantité synthétisée de matières azotées microbiennes pouvait être égale à 135 g/kg de matière organique digestible (MOD) ingérée à condition que le flux de matières azotées facilement dégradables en N ammoniacal dans le rumen soit au moins égale à 135 g de matières azotées fermentescibles par kg de MOD. Dans ce cas les aliments peuvent prendre la valeur PDIE. Si le flux est inférieur à 135 g la quantité de matière azotée microbienne équivaut à ce flux et il n'est plus proportionnel à la quantité de matière organique digestible ingérée, dans ce cas les aliments prennent la valeur PDIN.

Mais il a été observé que la digestion des constituants organiques (cellulosiques, amylacés) n'était pas modifiée tant que l'apport de matières azotées fermentescibles par la ration n'était pas inférieur à 110 g d'N x 6,25 par kg de MOD dans le cas des vaches laitières alimentées selon leurs besoins énergétiques et azotés; ce qui équivaut à un apport PDIE - PDIN $\leq$ 14 g par kg MOD ou 12 g/ UFL pour des

rations à concentration énergétique élevées.

A partir des quantités de MOD et d'azote ingéré et de la fermentescibilité de l'azote dans le rumen, il est donc possible de savoir si l'apport d'N fermentescible permet : 1) de maximiser la synthèse de protéines microbiennes; 2) de ne pas réduire l'activité fermentaire et la valeur énergétique de la ration.

En cas de déficit en N fermentescible il est alors possible de calculer la quantité de N non protéique à ajouter à la ration pour le combler.

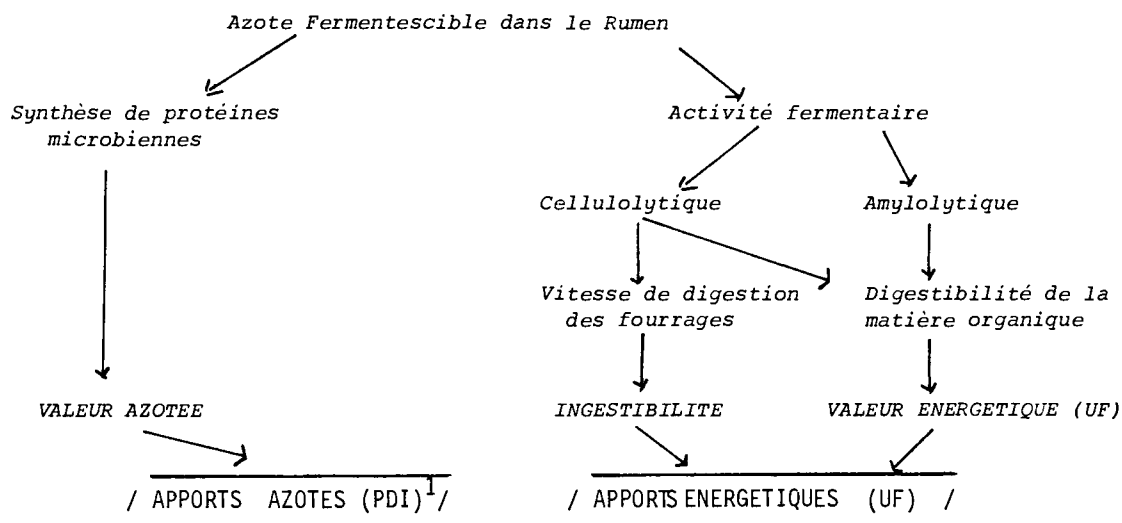


Schéma 1. Effets de l'apport d'azote fermentescible sur la digestion dans le rumen et la valeur énergétique et azotée des rations.

1/ In INRA, 1978, Alimentation des Ruminants.

Dans le système PDI, la fermentescibilité (F) de l'azote (N) des aliments a été estimé à partir de l'incubation in vitro durant 6 heures des aliments testés. La quantité d'N réellement non dégradable dans le rumen a été estimée à 0,65 N non dégradable in vitro. Cette valeur a été obtenue par régression à partir d'une compilation des résultats de la littérature sur les flux d'N duodénal, (VERITE et al., 1979).

Il est possible d'en déduire :

- 1) N de la ration fermentée en azote ammoniacal.
- $$= N - 0,65 N (1 - F)$$
- $$= N [F + 0,35 (1 - F)]$$

- 2) La quantité de N x 6,25 non protéique à ajouter à la ration : pour maximiser la synthèse d'N microbien
- $$= 135 \text{ MOD} - 6,25 \text{ N } \left[F + 0,35 (1 - F) \right]$$

Le tableau 1 fournit la quantité de matière azotée non protéique (N x 6,25) à ajouter à la ration selon la digestibilité de la matière organique, la fermentescibilité des matières azotées dans le rumen et la teneur en matières azotées de la ration.

Dans le système PDI cet apport d'ANP peut être très facilement calculé; il correspond à :

$$\text{apport de la source d'ANP} = \frac{\text{PDIE} - \text{PDIN}}{\text{Valeur PDIN de la source d'ANP}}$$

En cas d'utilisation d'ANP dans la ration, on admet par mesure de sécurité que cet apport doit être réalisé que ce soit pour maximiser la valeur PDI de la ration (valeur PDIE) ou pour éviter une baisse de la digestibilité et des quantités ingérées.

TABLEAU 1

Quantité de matières azotées non protéiques (N x 6,25) à ajouter (g par kg MS) selon la digestibilité de la matière organique (d MO), la fermentescibilité de l'azote et la teneur en matières azotées (MAT) de la ration 1/

Fermentescibilité de l'azote		50			70		
d MO		50	65	80	50	65	80
MAT	% MS						
4		45	65	85	35	55	75
6		35	55	75	20	40	60
8		25	45	65	10	30	45
10		15	35	55		15	30
12		5	25	45			15
14			15	35			
16			5	25			
18				15			
20				5			

1/ In INRA, 1978, Alimentation des Ruminants.

3) Niveau optimum d'apport N fermentescible aux vaches laitières :

Les rations hivernales pour vaches laitières à base d'ensilage de maïs actuellement très utilisées en France conduisent à un déficit en azote fermentescible du fait 1) de la faible teneur en matière azotée du maïs ensilage et de la fermentescibilité peu élevée de l'azote et 2) de sa teneur élevée en matière organique digestible. Pour maximiser la valeur PDI, les calculs (cf. précédemment) conduisent à recommander un apport supplémentaire de 160 g d'urée par vache et par jour aux animaux faibles producteurs qui n'ont pas besoin d'aliments protéiques complémentaires (VERITE, 1978). Pour les vaches qui doivent recevoir un aliment énergétique

et protéique de complément, la quantité d'urée à ajouter va dépendre de la fermentescibilité des protéines des tourteaux utilisés comme complément. Dans les essais conduits au Laboratoire de la Production Laitière de l'INRA de Theix, on a cherché à réduire l'apport de tourteaux en les traitant par l'aldéhyde formique. Mais en raison de la fermentescibilité plus faible de l'azote des tourteaux traités que celle des tourteaux normaux, le déficit en N fermentescible se trouve accru; d'où la nécessité d'accroître les apports d'urée. Dans 2 essais effectués en 1975 et 1976 sur 50 et 40 vaches en lactation (VERITE, 1978) on a cherché à déterminer les apports optimum d'urée en complément de rations à base d'ensilage de maïs et de tourteaux tannés et d'aliment énergétique distribué tous 3 en quantité limitée. Dans chacun des 2 essais (tableau 2) les quantités moyennes ingérées étaient identiques pour les différents lots qui recevaient par ailleurs des quantités différentes d'urée, 0, 70 et 145 g par vache et par jour dans l'essai I, et 0, 50, 120 et 200 g par vache et par jour dans l'essai II. En conséquence, les taux de matières azotées ont varié de 11 à un peu plus de 14 %. (de la matière sèche). Les apports de PDIN ont été équivalents à ceux de PDIE lorsque la dose d'urée a été la plus élevée, ce qui signifie que les apports de matières azotées fermentescibles $N \times 6,25$ correspondaient à la valeur de la synthèse microbienne (135 g par kg de MOD).

TABLEAU 2

Effet sur la valeur énergétique d'une ration 1/ à base
d'ensilage de maïs, céréales, pulpes et tourteaux tannés
d'un apport supplémentaire d'N fermentescible (urée) :
8 à 10 vaches par lot, périodes expérimentales de 12 à 15 semaines

Urée (g/jour) 2/	ESSAI I			ESSAI II			
	0	70	145	0	50	120	200
Matières azotées % MS	11,2	12,6	14,1	11,3	12,0	13,1	14,3
Apports PDI : . PDIN	1088	1200	1317	1143	1289	1410	1510
. PDIE	1291	1295	1288	1417	1472	1504	1470
Lait 4 % (kg)	17,3	17,6	18,1	20,3	21,7	21,4	21,6
Variation poids vif (g/jour)	-96	+12	-19	-19	+67	+196	+261
UFL/kg MS de la ration 3/	0,78	0,81	0,83	0,85	0,89	0,91	0,91

1/ Ensilage de maïs en quantité limitée (10,4 kg MS dans l'essai I, II, 5 kg MS dans l'essai II). Aliment concentré énergétique (céréales - pulpes) : 4,4 kg MS. Tourteaux tannés (Soja 1/2 - Colza 1/2) : 0,36 kg MS dans l'essai I, 0,60 kg dans l'essai II.

2/ Urée mélangée à l'ensilage de maïs au moment de la distribution.

3/ Calculé d'après les besoins (0,43 UFL/kg lait 4 % et 3,5 UFL/kg gain de poids vif).

TABLEAU 3

Effet sur la digestibilité d'une ration 1/ à base d'ensilage de maïs, de céréales, pulpes et tourteaux tannés d'un apport supplémentaire d'N fermentescible (urée) :
4 vaches fistulées en lactation, carré latin

Urée (g/jour) 2/	ESSAI I			ESSAI II			
	0	65	140	0	50	115	180
Matières azotées % MS	10,8	12,2	13,7	11,4	12,2	13,7	15,2
Apports PDI : . PDIN	949	1091	1217	976	1096	1215	1323
" . PDIE	1153	1191	1202	1171	1220	1235	1248
N-NH ₃ Rumen (mg/100 ml) 3/	4,8	7,6	12,1	2,8	8,1	11,9	17,2
Digestibilité de la matière sèche %	63,5	64,3	65,5	63,0	65,2	66,1	67,9

1/ Ensilage de maïs en quantité limitée (6,6 kg MS), aliment concentré énergétique 5,3 kg MS, Essai I - 4,4 kg, Essai II. Tourteaux tannés (0,16 kg MS Essai I, 0,35 kg MS Essai II).

2/ Urée mélangée à l'ensilage de maïs au moment de la distribution.

3/ Moyenne de 5 prélèvements entre les distribution du matin et du soir.

Dans l'essai I, la production de lait 4 % a été significativement accrue de 0,8 kg pour les deux niveaux extrêmes d'urée et le gain de poids vif a été légèrement amélioré. Dans l'essai II, la production de lait ne s'est accrue (de 1 kg) que pour l'apport de 50 g d'urée; les apports plus élevés d'urée n'ont pas conduit à un accroissement supplémentaire de la production de lait mais à une amélioration nette du gain de poids vif (négatif pour le lot sans urée et de plus de 200 g par jour pour le lot avec 200 g d'urée).

On peut attribuer l'accroissement de production de lait et de gain de poids vif à deux causes possibles :

1) à l'augmentation des apports de protéines digestibles dans l'intestin (PDI) suite à une augmentation de la quantité de protéines microbiennes synthétisées. Dans le système PDI, les apports de PDI calculés (PDIN) étaient assez nettement inférieurs aux besoins PDI des animaux dans les lots recevant les apports d'urée les plus bas. La mesure des flux d'N duodénal sur des vaches en lactation recevant les mêmes régimes à base d'ensilage de maïs ont d'ailleurs montré que la quantité de protéines (N non ammoniacal) passant au niveau du duodénum augmentait significativement avec l'apport d'urée (tableau 4). L'augmentation a été de l'ordre de 10 à 15 % lorsque l'apport d'urée s'est accru de 0 à 140 ou 180 g par vache et par jour, et le taux azoté correspondant de la ration de 11 à 14-15 %. (Résultats non publiés);

2) à l'augmentation des apports énergétiques consécutivement à une augmentation de la digestibilité de la matière organique dans le rumen. En effet, avec les vaches en bilan digestif qui ont reçu les mêmes rations que celles des essais d'alimentation I et II, la digestibilité de la matière organique s'est

accrue de 2 points dans l'essai I entre 0 et 140 g d'urée et de près de 5 points dans l'essai II, entre 0 et 180 g d'urée (tableau 3). La digestibilité la plus élevée a été observée pour un apport de PDIN équivalent ou peu inférieur à celui de PDIE, c'est-à-dire pour un apport de matières azotées fermentiscibles dans le rumen équivalent (ou peu inférieur) à 135 g par kg de MOD.

TABLEAU 4

Influence de l'apport d'urée dans des rations déficitaires en N fermentescible sur le flux d'azote à l'entrée du duodénum

	ESSAI I			ESSAI II			
g Urée/vache/jour	0	65	140	0	50	115	180
g N ingéré/kg MOD 1/	0						
- urée	0	3,8	7,8	0	3,0	6,0	9,1
- Tourteaux tannés	1,3	1,6	1,2	3,3	3,3	3,3	3,3
- TOTAL	28,7	31,8	34,9	30,2	31,5	34,2	36,7
Flux d'N g/kg MOD à l'entrée du duodénum	33,3	36,2	36,2	32,3	35,0	35,5	36,7

1/ MOD = Matière organique digestible.

Il semble donc bien que l'amélioration des performances de production de lait et de croît des vaches laitières doive être attribuée pour une part assez importante à une activité fermentaire accrue dans le rumen et consécutivement à une digestion plus efficace de la matière organique.

En cas de distribution ad libitum du fourrage (ensilage de maïs) il aurait pu en résulter également un niveau d'ingestion accru et une amélioration plus importante encore des performances. On observe d'ailleurs dans le lot sans urée de l'essai II une ingestion plus faible d'ensilage de maïs, certaines vaches ayant fait des refus bien que l'ensilage soit distribué en quantité limitée. Les augmentations de digestibilité (près de 5 points) sont semblables à celles obtenues avec des rations équivalentes à base d'ensilage de maïs par WOHIT et CLARK (1978) entre 11,2 et 13,6 % de matières azotées. HUBER (1975) a obtenu des accroissements importants de près de 30 % des quantités de matière sèche ingérées avec des rations également semblables à base d'ensilage de maïs, consécutivement à un apport supplémentaire de 200 g d'urée par vache et par jour et d'autres compléments azotés protéiques faisant passer le taux azoté de la ration de 8,5 à 13,5 %. Plus récemment, KWAN et al. (1977) ont obtenu des accroissements à la fois de la digestibilité, et du niveau d'ingestion de plus de 2 kg de matière sèche par vache et par jour, consécutivement à un apport supplémentaire d'urée dans la ration qui faisait passer le taux azoté de 13,9 à 16,6 %. Comme dans les essais que nous avons conduits avec les tourteaux traités à l'aldéhyde formique, les compléments protéiques utilisés par ces auteurs étaient peu fermentiscibles.

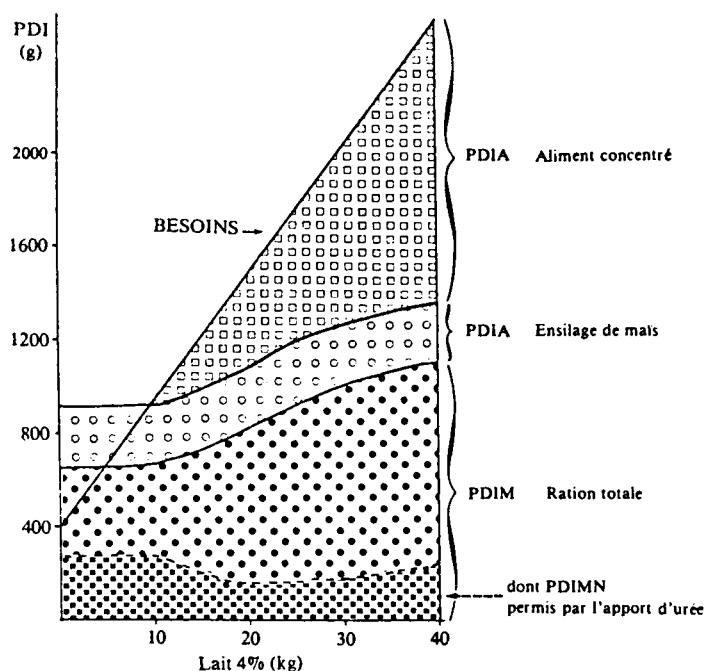
II. EFFET DE L'APPORT AZOTE AMINE ET INTERACTION AVEC L'APPORT ENERGETIQUE

1) Importance des besoins azotés et possibilités de les satisfaire :

Les besoins en azote aminé (PDI) des vaches laitières s'accroissent plus rapidement avec le niveau de production que les besoins énergétiques, en prenant comme niveau de base les besoins d'entretien. Les protéines microbiennes qui sont fonction principalement de la quantité d'énergie ingérée peuvent assurer 75 % des besoins azotés (PDI) pour une vache qui produit 10 kg de lait, mais seulement 50 % pour une vache qui produit 30 kg de lait si elle n'est pas sous-alimentée en énergie (Fig. 1) et seulement 35 à 40 % pour une vache de même production sous-alimentée en énergie, comme c'est fréquemment le cas en début de lactation.

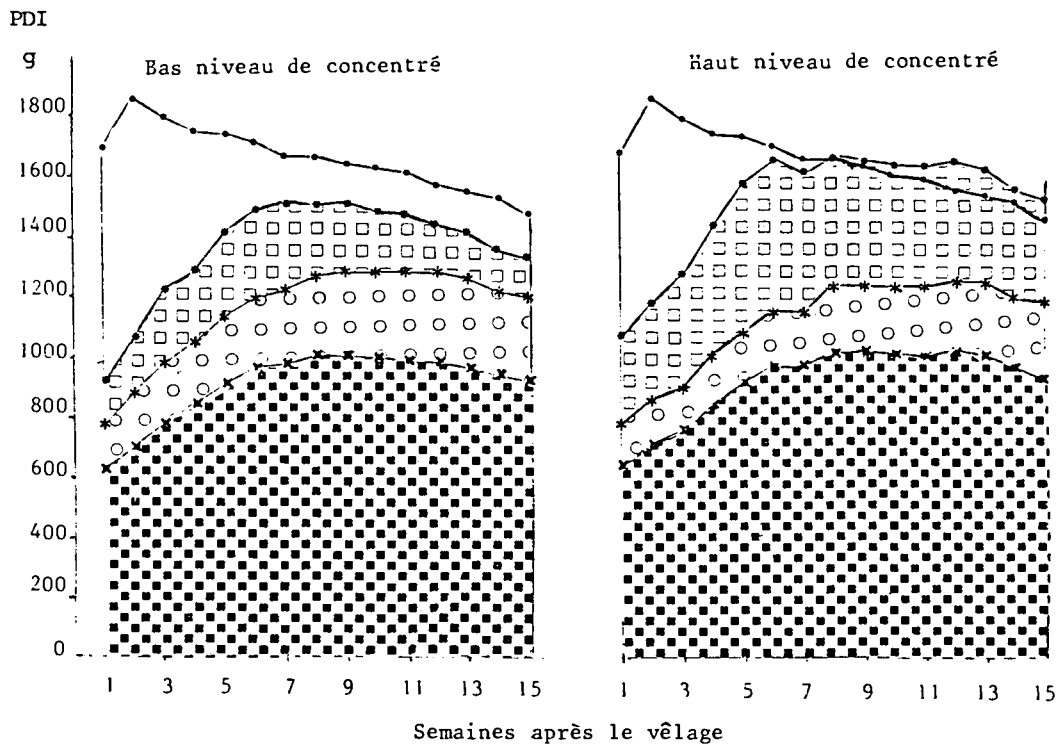
Le complément pour couvrir les besoins de l'animal devra être apporté par les protéines non dégradées dans le rumen en provenance de l'aliment (dites PDIA dans le système PDI). L'apport de PDIA du fourrage étant relativement constant quel que soit le niveau de production, l'apport PDIA de l'aliment concentré complémentaire devra croître très rapidement avec le niveau de production. Dans l'exemple choisi avec une ration d'ensilage de maïs, l'apport de PDIA de l'aliment concentré devra être 4 fois plus élevée pour 30 kg de lait que pour 15 kg de lait produit par vache et par jour.

Les possibilités de faire varier l'apport d'N aminé au niveau intestinal vont dépendre non seulement de la teneur mais aussi de la fermentescibilité des protéines de l'aliment concentré dans le rumen. C'est la raison pour laquelle le traitement à l'aldéhyde formique des protéines alimentaires est apparu comme un des moyens de satisfaire les besoins élevés d'N aminé chez les vaches fortes productrices. Le traitement d'après les résultats obtenus à l'étranger (KAUFMANN, 1977; TAMMINGA, 1976; VERITE et al., 1977) a permis d'accroître la quantité d'azote entrant dans le duodénum de 40 g (en moyenne) et jusqu'à 60 g par 100 g d'azote des tourteaux traités lorsque les sources azotées utilisées sont très dégradables (caséine, tourteau d'arachide, blé); et de 20 à 40 g pour du tourteau de soja moins dégradables. Lorsque le traitement a été effectué dans de bonnes conditions, la digestibilité intestinale de l'azote n'a pas été modifiée par le traitement et dans ces conditions le remplacement de 1 kg de tourteau normal par 1 kg de tourteau traité a permis en moyenne d'accroître la production de lait d'environ 1 kg (VERITE et JOURNET, 1977).



Vaches de 600 kg de poids vif, ingérant 13 kg de matière sèche d'ensilage de maïs additionné d'urée. On a supposé que les vaches produisant 30 kg de lait ou plus étaient sous-alimentées en énergie.

Fig. 1 Evolution, en fonction du niveau de production laitière, des besoins PDI et des apports PDI d'origine microbienne (PDIM) et d'origine alimentaire (PDIA).



- ■ ■ Protéines microbiennes PDIM
- ○ ○ Protéines de l'ensilage de maïs non dégradées dans le rumen (PDIA)
- □ □ Protéines de l'aliment complémentaire (20 % tourteau de soja, 80 % d'orge) non dégradées dans le rumen (PDIA)
- Déficit en PDI

Fig. 2 Variations en début de lactation des besoins azotés et des apports d'origine microbienne et alimentaire 1/.

(Vaches produisant environ 30 kg de lait au pic de production et recevant un régime à base d'ensilage de maïs complétement par un niveau haut ou bas d'apport d'aliment complémentaire).

1/ Protéines digestibles dans l'intestin (PDI)

2) Importance du déficit en N aminé en début de lactation

Bien que la production laitière s'accroisse jusque vers la 4 à 5ème semaine après le vêlage, la quantité de protéines du lait secrété est maximum dès le vêlage en raison du taux protéique élevé du lait. Inversement, l'apport de protéines alimentaires et microbiennes est le plus faible après le vêlage et évolue ensuite de façon inverse aux besoins de l'animal.

L'apport de protéines microbiennes est faible parce que la capacité d'ingestion des vaches et consécutivement l'apport d'énergie sont faibles. L'apport de protéines alimentaires (PDIA) est faible aussi en rapport avec les niveaux faibles d'ingestion de fourrages et d'aliment énergétique complémentaire.

Nous avons étudié sur 43 vaches multipares au cours des 15 premières semaines de lactation l'évolution des besoins azotés et des apports azotés dans le système PDI en décomposant ces dernières en deux fractions : 1) alimentaire (PDIA) et 2) microbienne (PDIM) (Fig. 2). Les animaux utilisés étaient soumis à deux traitements correspondant à deux niveaux d'apport d'aliments concentrés : 1 kg par 2,5 kg de lait au-dessus de 20 kg de lait 4 % pour le niveau bas, et au-dessus de 10 kg de lait à 4 % pour le niveau haut (au maximum de production). Les quantités de concentré ont été accrues progressivement de 3 kg de matière sèche (après le vêlage) à 4,7 kg (la 6ème semaine) pour le niveau bas, et de 5 kg de matière sèche à 8,5 kg pour le niveau haut. De l'ensilage de maïs à stade avancé de maturité, à plus de 35 % de matière sèche était par ailleurs offert à volonté. Les deux niveaux d'apport de concentré ont été combinés avec deux niveaux d'apports azotés selon un dispositif factoriel. Dans le niveau azoté Bas, les vaches ont reçu un concentré de même composition durant tout l'essai; dans le niveau azoté Haut, les besoins en PDI des animaux ont été satisfaits en utilisant des tourteaux traités à l'aldéhyde formique et en changeant la proportion de tourteaux dans le complément (cf. ci-après).

Les besoins en PDI ont été calculés pour chacun des deux niveaux d'apport de concentré d'après la production laitière des vaches qui ont reçu le niveau azoté Haut et qui ont produit le plus de lait.

D'après le calcul des apports PDI, l'apport de protéines microbiennes (PDIM) en première semaine de lactation (600 g/vache/jour) ne satisfait que la production de 5 kg de lait à 3,33 % de protéines (en plus des besoins d'entretien) en raison de la faible ingestion de matière organique digestible (ensilage de maïs + aliment concentré). L'apport de protéines microbiennes s'accroît ensuite de 65 % entre la première et la 8ème semaine de lactation en raison de l'accroissement des quantités ingérées d'ensilage et d'aliment concentré. Il permet la production de 12 kg de lait en 8ème semaine. Dans le même intervalle, la quantité de protéines alimentaire (PDIA) en provenance de l'ensilage de maïs s'accroît : 150 g en première semaine et près de 300 g en 8ème semaine, ce qui équivaut aux besoins de production respectivement de 3 à 6 kg de lait. En conséquence le déficit de PDI qui doit être couvert par les protéines alimentaires de l'aliment complémentaire est très important durant les 3 premières semaines de lactation et il correspond alors à 50 % des besoins PDI de l'animal. Ce déficit décroît rapidement par suite de l'évolution inverse des besoins et des apports de protéines (microbiennes + ensilage de maïs).

La possibilité de couvrir le déficit azoté par les protéines (PDIA) de l'aliment concentré va dépendre :

- 1) de sa teneur en protéines
- 2) de la dégradabilité des protéines
- 3) du niveau de complémentation en aliment concentré.

Si on utilise un concentré de composition constante (19 % de protéines; 20 % de tourteau de soja + 80 % de maïs grain), la Fig. 2 montre : 1) qu'au niveau bas d'aliment concentré, le déficit reste important durant les 3 premiers mois de lactation*; 2) qu'avec le niveau haut d'aliment concentré le déficit est toujours très important les premières semaines de la lactation mais qu'il dure moins longtemps (5 à 6 semaines).

*par rapport à la production potentielle des vaches bien alimentées en azote.

TABEAU 5

**Effet combiné du niveau des apports azotés (PDI) et
énergétiques au cours des 8 premières semaines de la lactation
(Niveau haut d'apport azoté = satisfaction
des besoins PDI à tout moment)**

Niveau d'apport énergétique	Haut		Bas	
Niveau d'apport azoté	Haut	Bas	Haut	Bas
Nombre d'animaux	11	10	11	8
Quantités ingérées (kg MS)				
. Ensilage de maïs	7,64	7,44	11,39	10,93
. Concentré énergétique	6,90	8,46	1,58	2,45
. Tourteaux tannés	1,34	0,16	2,35	1,05
. Urée - minéraux (1/1)	0,37	0,36	0,38	0,37
Apport énergétique (UFL)	14,7	14,9	13,9	13,1
Apport azoté (PDI) - g -	1778	1532	1772	1387
Production réelle				
. Lait 4 % (kg)	26,2	24,5	28,1	23,5
Production corrigée ⁽¹⁾				
. Lait (kg)	26,9	23,6	27,5	24,2
. Lait 4 % (kg)	26,4	23,3	27,9	24,7
. Taux butyreux ‰	39,1	39,3	42,0	41,4
. Taux protéique ‰	33,5	33,3	32,6	32,9
Poids vif (kg)	590	574	599	555
Variation de poids vif vide (2) (maximale) - kg	43	46	55	35
% Réussite en 1ère insémination	54	70	36	37
Nombre d'insémination/insémination fécondante	1,9	1,5	2,2	1,6

(1) Par analyse de covariance sur les 8 premières semaines de lactation précédente

(2) Poids vif corrigé pour les variations de contenu digestif estimées à 4,5 kg pour une variation de 1 kg de matière sèche ingérée.

TABLEAU 6

Effet combiné du niveau des apports azotés et du niveau d'apport de complément énergétique au cours des 8 premières semaines de la lactation, avec distribution ad libitum du fourrage (ensilage de maïs)

Niveau azoté haut : couverture des besoins azotés à tout moment au cours des 8 semaines

Niveau d'apport de complément énergétique	Haut		Bas	
Niveau d'apport azoté	Haut	Bas	Haut	Bas
Nombre d'animaux	13	12	11	12
Quantités ingérées (kg MS)				
. Ensilage de maïs	11,1	8,5	13,8	12,0
. Concentré énergétique	5,9	7,3	2,2	3,4
. Tourteaux tannés	1,4	0,2	2,0	0,6
. Urée - minéraux (1/1)	0,4	0,4	0,4	0,4
Apport énergétique (UFL)	16,3	14,3	15,6	13,9
Apport azoté (PDI) - g	1842	1385	1876	1393
Production réelle				
. Lait 4 % (kg)	27,5	25,7	27,9	25,5
Productions corrigées ⁽¹⁾				
. Lait (kg)	27,9	25,3	28,1	25,6
. Lait 4 % (kg)	27,8	25,1	27,8	25,8
. Taux butyreux (‰)	40,3	40,1	39,7	41,1
. Taux protéique (‰)	32,6	31,2	31,8	31,0
Poids vif (kg)	602	585	609	568
Variation de poids vif vide ⁽²⁾ maximale - kg.	48	72	53	57
% Réussite en 1ère insémination	84,6	41,7	72,7	50,0
Nombre d'insémination/insémination fécondante	1,25	1,75	1,45	1,91

(1) Par analyse de covariance sur les 8 premières semaines de lactation précédentes.

(2) Poids vif corrigé pour les variations de contenu digestif estimées à 4,5 kg pour une variation de 1 kg de matière sèche ingérée.

3) Effet d'une couverture précoce des besoins en N aminés des vaches laitières en début de lactation sur la production de lait, la capacité d'ingestion, la reproduction et l'état sanitaire des animaux : Interaction avec le niveau des apports énergétiques.

Les besoins énergétiques des vaches laitières en début de lactation ne peuvent pas être satisfaits en raison de la faible capacité d'ingestion des vaches et de l'impossibilité d'accroître la concentration énergétique nette des rations au-delà d'un certain niveau; et ce déficit énergétique s'accroît avec le niveau de production des vaches. En revanche, les besoins azotés peuvent être facilement satisfaits par un apport élevé de complément protéique peu dégradable dans le rumen. Cependant, la satisfaction des besoins azotés à tout moment au cours des deux à trois premiers mois de la lactation nécessite d'ajuster très fréquemment ces apports semaine par semaine.

Les essais conduits au Laboratoire de la Production Laitière de l'INRA de Theix (REMOND et al., résultats non publiés) ont eu pour objectif de mesurer les effets d'une couverture immédiate des besoins azotés en début de lactation comparativement à la technique habituelle de rationnement qui conduit à un déficit azoté les premières semaines. Les apports et les besoins ont été estimés dans le système PDI. Le traitement à l'aldéhyde formique des protéines des tourteaux a été utilisé de façon à pouvoir satisfaire sans difficulté les besoins azotés après le vêlage des vaches les plus fortes productrices. Les tourteaux ont été composés d'un mélange pour moitié de tourteaux de soja et de colza, en raison de leur richesse respective en lysine et en méthionine, les 2 principaux acides aminés limitants.

Dans l'essai I (Tableau 5), la comparaison des 2 niveaux d'apport azoté a été effectuée à même niveau d'apport énergétique en limitant les apports d'aliments concentrés et de fourrages (ensilage de maïs), et chacun des 2 niveaux d'apport a été étudié à 2 niveaux d'apports énergétiques de façon à mesurer l'interaction entre le niveau d'apport énergétique et le niveau d'apport azoté : l'effet d'une couverture précoce des besoins azotés en début de lactation dépend-il de l'importance de la sous-alimentation énergétique ?

Dans l'essai II, les 2 niveaux d'apport azoté ont été étudiés dans le cas d'une distribution ad libitum des fourrages, de façon à mesurer les effets éventuels de l'apport azoté sur la capacité d'ingestion des animaux et consécutivement sur l'ingestion volontaire d'énergie. Chaque niveau d'apport azoté a été étudié à 2 niveaux d'apport d'aliments concentrés (Tableau 6) : l'effet d'une couverture précoce des besoins azotés en début de lactation est-il différent selon le niveau de la complémentation en aliment concentré ?

- A même niveau d'apports énergétiques (distribution en quantité limitée des fourrages)

Avec le niveau azoté haut les productions de lait 4 % ont été supérieures significativement en moyenne de 3 kg, soit d'environ 12 % par rapport au niveau azoté bas. Les teneurs en matières grasses et en protéines n'ont pas été modifiées. Les accroissements de production ont été identiques quel que soit le niveau énergétique haut et bas. Ils ont été obtenus à même variation de poids vif vide pour le niveau énergétique haut mais avec un accroissement de la perte de poids vif vide après le vêlage pour le niveau énergétique bas.

Les performances de reproduction bien qu'obtenues sur un nombre faible d'animaux semblent moins bonnes avec le niveau azoté haut qu'avec le niveau azoté bas. On peut également remarquer qu'à même niveau d'apport azoté les performances de

production (lait 4 %) n'ont pas été meilleures avec le niveau énergétique haut qu'avec le niveau énergétique bas; elles ont même été inférieures mais non significativement. En fait, le niveau énergétique haut a correspondu à une proportion d'aliment concentré plus élevé dans la ration (50 %) que le niveau énergétique bas (25 %). Les performances de production les meilleures ont été obtenues en combinant le niveau énergétique bas avec le niveau azoté haut.

- A même niveau d'apport d'aliment complémentaire énergétique, avec distribution ad libitum du fourrage (ensilage de maïs) :

Avec le niveau azoté haut, les productions de lait 4 % ont été supérieures significativement en moyenne de 2,4 kg soit d'environ 10 % par rapport au niveau azoté bas. La composition du lait n'a pas été modifiée. Les accroissements de production ont été identiques quel que soit le niveau d'apport du complément énergétique haut et bas. Ils ont été accompagnés en même temps d'un niveau d'ingestion plus élevé d'ensilage de maïs d'environ 2 kg de matière sèche, d'une perte de poids vif plus faible après le vêlage (principalement pour le niveau énergétique haut) et d'une amélioration des performances de reproduction et d'état sanitaire (diminution des troubles de l'ingestion).

Ces effets sur la reproduction et les variations de poids vif qui sont inverses de ceux observés dans l'essai précédent peuvent s'expliquer par l'accroissement du niveau des apports énergétiques (1,8 UFL) qui accompagne l'accroissement du niveau des apports azotés (environ 450 g de PDI).

Paradoxalement, l'accroissement du niveau d'apport d'aliment complémentaire n'a pas provoqué d'accroissements des apports énergétiques en raison de la substitution entre l'ensilage de maïs et l'aliment complémentaire; et la production laitière est restée inchangée. Alors que l'accroissement des apports azotés a eu pour effet de stimuler l'appétit des vaches et d'accroître de cette façon le niveau des apports énergétiques, avec des effets positifs sur l'ensemble des performances des vaches laitières : production de lait, état corporel, reproduction, état sanitaire. Les résultats illustrent l'interférence étroite qui existe chez les vaches en début de lactation entre la nutrition azotée et la nutrition énergétique. Il semble bien que cette interférence ait lieu au niveau métabolique, l'effet de l'azote devant être attribué à l'apport d'acides aminés et non pas à l'apport d'azote fermentescible dans le rumen qui a été suffisant dans tous les traitements grâce à l'apport de l'urée.

CONCLUSION

Les apports énergétiques et azotés apparaissent très interdépendants. En effet, dans certaines conditions, les apports azotés influent sur les apports énergétiques et leurs effets peuvent en partie être attribués à ces derniers et inversement.

Ces interrelations ont lieu essentiellement au niveau de la digestion dans le rumen. Les rations pour vaches laitières à base de fourrages à forte concentration énergétique riches en amidon et pauvres en azote peu fermentescible types ensilages de maïs fournissent les exemples les plus significatifs de ces interactions énergie-azote. Une supplémentation insuffisante par des sources d'azote fermentescible, azote facilement hydrolysable en ammoniacque, conduit à une diminution des performances de production par suite d'une réduction à la fois des apports azotés (par suite d'une diminution de la quantité de protéines microbiennes synthétisées) et énergétiques (par suite d'une diminution de la digestion de la matière organique dans le rumen) et parfois de l'ingestion en cas d'alimentation ad libitum.

Avec de telles rations il apparaît en outre que l'emploi de protéines protégées de la dégradation dans le rumen en vue soit d'améliorer les performances laitières, soit de réaliser des économies de protéines nécessitent l'emploi simultané d'azote non protéique. L'association de protéines protégées et d'azote non protéique permet de réunir les conditions optimum d'une bonne nutrition tant azotée qu'énergétique, tout en minimisant les apports de protéines alimentaires (tourteaux).

La faible ingestion d'énergie peut être aussi la cause d'un déficit azoté important par suite d'une réduction de la synthèse de protéines microbiennes. L'exemple le plus significatif est fourni par les vaches laitières en début de lactation qui ont une très faible capacité d'ingestion. L'incidence en est d'autant plus grave qu'à cette période, les besoins azotés sont maximum.

Dans ces conditions, un apport très important de protéines peu solubles pour couvrir le déficit d'azote aminé, et d'azote non protéique pour stimuler la digestion dans le rumen, a pour effet : 1) d'accroître la quantité synthétisée des constituants du lait, matières grasses et matières protéiques et 2) de stimuler l'ingestion volontaire d'énergie, en cas d'alimentation ad libitum.

Bien que la vache soit capable de mobiliser les protéines corporelles labiles en début de lactation et d'économiser l'azote en réduisant l'excrétion urinaire, il semble donc préférable d'éviter cette mobilisation. L'effet des apports azotés en début de lactation doit être attribué principalement à la fourniture des acides aminés les plus indispensables dont la méthionine; mais le rôle des acides aminés notamment des acides aminés non indispensables comme sources de chaînes carbonées et donc d'énergie et de glucose à la mamelle n'est pas exclu et reste à démontrer.

A l'inverse de ce qui a pu être observé en milieu de lactation, l'effet de l'apport azoté (azote aminé) en début de lactation n'a cependant pas paru dépendre du niveau des apports énergétiques. L'accroissement de production obtenu a été identique que les vaches laitières soient moyennement ou fortement sous-alimentées en énergie.

En outre, il est apparu que les nouveaux systèmes d'expression des besoins et des apports azotés permettent de tenir compte des relations énergie/azote qui existent au niveau digestif. En particulier, avec le système PDI utilisé en France, il a été possible de quantifier les déficits azotés du début de la lactation et ses variations très rapides au cours des 2 premiers mois, et d'y pallier de façon efficace en améliorant les performances de production, de reproduction et l'état sanitaire des vaches laitières.

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The Significance of Protein/Energy Relationships in the Practical Feeding of Dairy Cattle

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A marked increase in the output of food of animal origin, particularly milk and meat (Czechoslovakia per capita consumption levels: 86 kg meat and 250 kg milk and dairy products), on the basis of the planned area under fodder crops and with the available import sources of concentrates, can only be achieved through increasing the intensity of the production of bulk forage which is the main source for cattle nutrition.

The intensification of production through raised application rates of fertilizers, mainly nitrogenous, leads to a change in the mutual relationships of nutrients, mainly resulting in an altered energy/protein relationship. The geographical position of Czechoslovakia and the altitudes prevailing in this country suggest that the production conditions in about two-thirds of the territory are suitable for the production of high-protein fodder crops (lucerne, clover, grass stands), rather than for glycide-type fodder, whereas in the somewhat more arid southern part of the territory (mainly in the non-irrigated regions), glycide-type forage is produced, particularly silage maize. This differentiation of the conditions of obtaining basic forage for cattle necessitates, on the one hand, addition of protein to the ration and on the other hand it makes it necessary to solve the problems of the lack of energy. The latter problem appears to be much more significant, since an energy deficit with surplus protein affects the animals' performance, and - which is a much greater problem - causes alimentary problems and may even affect reproduction and health in general.

This is the reason why the relationship between protein and energy is so important in the plan of research and why its problems are being investigated in an exhaustive manner from the production of forage, through feed preservation, up to the consequences in cattle nutrition.

It has been found that when the lacking part of the protein is replaced in the ration by synthetic nitrogen, or when the animals are given bulk forage with a higher protein content from intensive fertilization, or fodder preserved by ensiling, one basic problem arises: nutrition under the conditions of increased doses of non-protein nitrogen (NPN). Considering that the starting substance for the reverse synthesis of protein by rumen microbi is ammonia, the remaining nitrogen sources being of minor importance in proteosynthesis, then it becomes evident why it is so necessary to study the conditions for an optimum course of ruminal fermentation at an increased NPN supply.

It follows from the studies hitherto conducted that the nitrogenous supplies of dairy cows depend on the protein sources, on their solubility, and on the microbial protein synthesis level. The synthesis of microbial protein in the rumen is closely linked with glycide metabolism, providing not only the carbonaceous skeleton but also the energy needed for ammonia fixation.

However, for milk production it is of decisive importance to know how much nitrogenous substance is available to the cow for resorption in the small intestine. It has been demonstrated that the amount of metabolizable protein in the small intestine depends not only on the amount of N-compounds in the feed ration but also on their quality, manifesting itself, for instance, in an increased passage of undecomposed protein through the forestomachs, on the quality of conditions for microbial protein synthesis, on the level of the resorption of free amino acids, and so on.

It is often claimed in literature that grass stands have a high capacity for assimilating high doses of nitrogenous nutrients and for converting them into biologically valuable ruminant feed. We studied these problems (Kolár 1972, 1973, 1974, 1980), trying to find the effect of different levels of nitrogenous fertilization upon the properties of the stand as fodder and upon the possibility of using these properties. The trials were made on a pasture stand with the application of 0, 100, 200 and 400 kg N/ha.

The results of the variance analysis of data from four-year experiments indicate that graduated nitrogen application rates showed a significant influence on the chemical composition of the material produced. As known from literature, the content of nitrogenous nutrients was influenced most intensively (Table 1). It can be stated that up to a high fertilization rate (with precipitation rates of about 700 mm) both components of nitrogenous nutrients increase (protein as well as NPN), protein sharing about 60% of the total increase and NPN 40%. What deserves special attention is the increment of the soluble fraction of nitrogen compounds whose proportion increases from 32.2% to 52.6%. This is due to a rise in the proportion of non-protein nitrogen as well as amino acids, such as leucine, glutamic acid, arginine - all being involved in the production of plant globulins, and - on the other hand - to a decrease in the content of amino acids which make a significant contribution to the synthesis of insoluble prolamines.

The different application rates of nitrogenous fertilizers influenced not only nitrogen compounds but also the content of some components which significantly contribute to the energetic value (Table 2). Particular importance is attached to the decrease of the content of extractive non-nitrogenous substances, but the decrease in the fibre content - if the same vegetation state of the stand was maintained during harvesting - was not so great as expected. Detailed analysis demonstrated that a decreasing proportion of lignin in the stand is particularly involved in the drop.

The determination of apparent digestibility in vivo (Table 3) demonstrated a significant influence of the chemical regime of the stand on the digestibility of some nutrients. This influence was most significantly exerted on the digestibility of nitrogen compounds, owing to an increasing content of these substances in general and to a rise in their soluble fraction in particular (this fraction shows a high share of "digestibility"). On the other hand, a significant decrease of digestibility was recorded in nitrogen-free extractive substances. This may be due to a general decrease in the content of nitrogen-free extractive substances and to a widening ratio between the content of N-compounds and the sum of nutrients with a higher energetic value.

In order to get an at least partial picture of the conversion of nitrogen in the animal organism, nitrogen balances (Table 4) were calculated and a high retention of nitrogen was recorded with increasing levels of N-fertilization.

The decisive factor underlying the determination of the actual availability of nutrients in the feed is their productive efficacy, or their conversion effect. In a test with 16 cows (Table 5), divided into 4 groups, a constant amount of grass stand dry matter was given to the animals; the grass stand had been grown at different levels of nitrogenous fertilization. The ration contained 2.13 kg grass d.m. per 100 kg live weight with an addition of potato flakes which enabled (in keeping with the Czechoslovak standard of nutrient consumption) the achievement of a balanced ratio of nitrogen and energy (in starch units) in the control ration (with grass from stand with no nitrogenous fertilization), for the production of 16 litres of milk. The cows in the remaining groups were given a ration of iso-energetic value (each by its live weight), but with a different content of nitrogenous nutrients.

The experiment aimed at finding out the effect of varying protein and energy ratios on the production of milk by cows. In a thirty-day exact metabolic test with a 14-day preparatory period, the administered rations were found to have a diminishing production efficacy with increasing levels of the protein-energy quotient ($PEQ = \frac{\text{digest. N-comp.}}{\text{starch units}}$). As distinct from the theoretical assumption

of 16 kg of milk, the cows of the control group had an average milk yield of 16.32 kg, the cows of the first test group 16.5 kg, the second group 15.3 kg and the third group 14.12 kg.

The nitrogen balance (Table 6) confirmed not only a rise in the digestibility of the nitrogen compounds from stands fertilized with higher levels of nitrogenous fertilizers and an increased escape of the nitrogen taken up from protein of changed quality, but also the elimination of the nitrogen which is in a non-physiological ratio with energy, in the urine. The elimination of excess nitrogen takes place with metabolic losses of energy, and this was probably one of the most important causes of performance drop in the second and third group. The balance of nitrogen demonstrates that the cow organism was not able to use excess nitrogenous nutrients as an energy source. It can be assumed that also the passive nitrogen balance in the groups with a dose of 200 and 400 kg N per ha is not merely due to chance. What testifies to the adverse effect of an unsuitable protein/energy ratio is the marked reduction of the availability of nitrogen for milk production, expressed by the percentage of the nitrogen taken in, or digested.

Some of these problems have been explained by Venclo *et al.* (1979) who studies the effect of forage preservation on the change in the quality of nitrogenous substances and on the parameters of nitrogen metabolism. These tests included the examination of 60 feeds and their combinations in which the content of the soluble N-compound fraction was determined and, on the basis of the determination of apparent digestibility *in vivo* and analyses of rumen liquor, the dependence of bulk forage nitrogen utilization by ruminants on the quality of consumed nitrogen compounds and on the energy intake, was formulated.

The tested feeds were divided into the following five groups: green forage, hay, haylage, silage, dried material (hot-air-dried forage). Animals with an artificial rumen fistula were used for the experiments. The following findings were formulated on the basis of the results obtained:

In the determination of the content of the soluble fraction of nitrogen compounds, the two-stage method after Journet (1977) gives more exact results (repeatability) than the current one-stage method after Wohlt *et al.* (1973) (Table 7).

Silage and other fermented feeds contain a significantly higher proportion of the soluble fraction of nitrogen compounds, as compared with the feeds preserved by drying or with green forage. The following characteristics were determined in the set of the analysed feeds: the average content of soluble nitrogen fraction in green forage 40.4%, in hay 35.24%, in haylage 57.61%, in silage 61.43%, and in hot-air dried forage 42.34%.

A high interdependence was found between the digestibility of N-compounds and the intake of the soluble fraction of nitrogenous substances and energy which was evaluated by the calculation of the correlation coefficients and the regression equation coefficients. In the sets of green forage, hay and silage, a practically functional dependence was found between the content of total N-compounds and digestible N-compounds; in dried feeds and haylage a lower dependence was obtained owing to the heating of the material during processing.

green forage	$y = -1.19 + 0.828 x_1$	$r = 0.996$
hay	$y = -2.11 + 0.811 x_1$	$r = 0.985$
haylage	$y = -5.06 + 0.828 x_1$	$r = 0.913$
silage	$y = -2.93 + 0.868 x_1$	$r = 0.992$
dried material	$y = -3.92 + 0.836 x_1$	$r = 0.946$

In order to take into account the effect of the heating of haylage and dried feeds, another variable was included in the respective calculations and the dependence of digestible nitrogen was determined from the intake of nitrogen (x_1) and percentage of nitrogen insoluble in acid detergent (x_2) which is, in fact, a parameter of the degree of heating. This relationship can be expressed by the following:

$$y = 1.61 + 0.68 x_1 - 0.17 x_2$$

Naturally, an increased intake of nitrogen is accompanied by an increased urinary elimination of this element, and this is in close relationship with nitrogen digestibility and with the intake of the fraction of soluble nitrogen compounds. The following equations were determined for the relationship of the elimination of nitrogen with urine (y) to the intake of the fraction of soluble N-compounds (x_3):

green forage	$y = 0.48 + 1.670 x_3$	$r = 0.875$
hay	$y = 18.00 - 0.036 x_3$	$r = -0.024$
haylage	$y = 4.37 + 0.700 x_3$	$r = 0.592$
silage	$y = -1.06 + 1.260 x_3$	$r = 0.731$
dried material	$y = 14.90 + 0.080 x_3$	$r = 0.312$

These relationships can be ascribed to the high dependence of the digested nitrogen on the intake of soluble N-compounds. The values of the correlation coefficients are therefore insignificant in hay and dried material.

The amount of nitrogen retained in the organism of the animal is a parameter of the utilization of nitrogen compounds. Nitrogen retention shows only a low dependence on the amount of the nitrogen taken in and on the amount of nitrogen ingested. These conclusions are in keeping, for instance, with the data asserted by Egan and Kellaway (1971) who ascribe only 65% of the variability of nitrogen retention to nitrogen intake. It is demonstrated on the basis of the analysis of the relationship of nitrogen retention to different variables, that the strongest dependence is felt in the relation to the intake of metabolizable energy (x_4). This relation is expressed by the equation:

$$y = -5.31 + 0.0173 x_4 \quad r = 0.514$$

Müller (1973) alleges that retention is increased by 5.16 g N when energy intake is higher by 1 Mcal, and this is close to the 4.51 g level of N per 1 Mcal, or 1.08 g N per 1 MJ of metabolizable energy, determined in this trial.

These dependences were also evaluated on the basis of the change in the parameters of rumen liquor sampled prior to feeding and in the intervals of 45 min, 1.5, 3 and 6 hours after the end of feed intake. The dependences were evaluated from the values of the concentration of ammonia and nitrogen prior to feeding in the mentioned sampling intervals, and from the average per-hour output of ammonia. It can be stated that the amount of total nitrogen (mg%) in rumen liquor, produced per average hour, showed a significant dependence on nitrogen intake ($r = 0.412$), on the daily intake of digested nitrogen ($r = 0.434$), on the level of feed N-compound solubility in phosphate buffer ($r = 0.468$), and on the per-hour ammonia output ($r = 0.703$). The dependence between the amount of nitrogen taken in, nitrogen digested, and the soluble nitrogen fraction was evaluated as significant. On the basis of a detailed evaluation of the relationships it could be generalized that an increasing content of the soluble N-compound fraction in feeds is accompanied by increasing digestibility, associated with a higher ammonia level in the rumen liquor and with a higher urinary elimination of nitrogen. The N-compound digestibility coefficient is not, therefore, an objective parameter of the satisfaction of the physiological requirements of animals in the case of feeds with a high content of the soluble fraction of N-compounds, because part of the N-compounds taken in is liable to deamination in the rumen and is erroneously regarded as digestible. Then, the utilization of ammonia depends on the intake of available energy in the feed ration. It is therefore necessary in feed rations with a higher proportion of silage to increase the supplement of the readily available energy. The higher utilization rate of the nitrogenous substances of dried feeds (hay), compared with fermented feeds, can be attributed to a lower content of the soluble fraction of N-compounds and to the retention of water-soluble sugars which are fermented in silages.

The determination of the effect of energy intake upon the concentration of ammonia in rumen liquor included the calculation, by multiple regression, of the dependence of ammonia production (y) on the percentual content of nitrogen in organic matter (x_1) and the amount of digested matter (x_2) converted per kg WO.75.

$$y = 2.17 + 10.66 x_1 - 0.386 x_2 \quad r = 0.684$$

It follows from all this that the production of ammonia in rumen liquor depends on the content of nitrogen in the ration ($r = 0.930$) and decreases with the intake of organic matter ($r = 0.475$). These relationships are expressed in Graph 1 for different levels of ammonia production in the rumen. The content of ammonia in the rumen liquor increases with a rising content of nitrogen in the feed and vice versa, ammonia production decreases with increasing intake of digested organic matter. The knowledge of these relationships is necessary for the calculation of an effective dosage of NPN in the feed rations of ruminants; the system of digestible nitrogen compounds hitherto used in Czechoslovakia does not allow for a reliable calculation.

The research on the replacement of a lacking protein in feed mixtures in cow feed rations is mainly pursued by the Research Institute of Animal Production at Nitra, Slovakia, which is a co-ordinating centre for the utilization of NPN within the CMEA member countries.

It is recognized that from the view-point of cow feeding, the substitution for N-compounds mainly depends on

- N-compound content in the feed ration
- solubility of the feed N-compound in the forestomachs
- concentration of energy in the ration, particularly the proportion of readily soluble glycidies

Sommer A., Pejtás M. et al. (1980) conducted two trials with dairy cows to solve the problems of the replacement of N-compounds by synthetic sources, i.e. urea and urea phosphate, from the view-point of performance level and reproduction cycle in the cows. The trial was organized by the Latin-square method, and comprised 12 cows of the Black Spotted breed. The differences in the effects ensued from the different replacement of groundnut groats by urea and urea phosphate in feed mixtures (Table 8).

The bulk feed ration consisted of maize silage and lucerne haylage. The bulk forage dose was kept constant throughout the experiment, and the compared mixtures were rationed in amounts of 0.3 kg per litre of milk produced.

The highest consumption of feed mixtures per kg of milk produced was recorded in group D in which extracted groundnut groats were fully replaced by urea (Table 9). The mentioned consumption is higher by 28 g (8.4%) than in mixture A, by 39 g (12.11%) than in mixture B, and by 26 g (7.76%) than in mixture C. Increased nutrient consumption is in keeping with this increased feed mixture consumption.

In comparison with mixture A (Table 10) in which the cows produced 16.74 kg milk daily, the effect of mixture B was found to induce, on an average, the daily milk yield higher by 0.47 kg (2.81%), and that of mixture C induced an increase by 0.09 kg (0.54%). A milk yield reduced by 0.35 kg (2.09%) was the result of the effect of mixture D. These differences are not statistically significant from the view-point of the replacement of extracted groats by urea and urea phosphate.

The different composition of feed mixtures had no significant effect on the daily output and composition of milk and the differences show no trend of dependence on some of the effects. The same can be stated as to the content of urea in milk.

On the basis of the results of this experiment, another long-term experiment was conducted with 20 cows which were exposed to the experimental effects throughout the lactation period. The tested cows were given the production mixture (Table 11) with a complete replacement of extracted groats. Synthetic N-compounds shared 34% of the N-compounds of the feed mixture (urea 28%, urea phosphate 6%). The cows were given 440 g of mixture per litre of milk produced, in addition to the basic feed ration which contained current bulk feeds (maize silage - lucerne haylage).

The comparison of the performance of all cows (Table 12) in the control and experimental group revealed significant differences; the differences in milk composition did not reach the significance level. In the control group the daily milk yield was higher by 0.45 kg, i.e. 2.1%.

When higher exactness was required from the evaluation of the studied effects, it appeared necessary to analyse the obtained results separately in different lactation stages. The comparison of the first 76 days of lactation showed that the cows of the control group produced 25.32 ± 1.15 kg of milk, whereas the cows of the experimental group only produced 22.97 ± 0.83 kg of milk.

In the second stage of lactation (from the 77th to the 305th day), the differences in daily output decreased: the cows in the control group produced 13.94 ± 1.38 kg of milk, on average, and those in the experimental group 14.53 ± 1.18 kg of milk daily, on average. In comparison to the experimental group, the milk output in the control group was insignificantly lower by 4.1%.

During the study of different stages of lactation, no difference was recorded in the content of fat and protein in milk ascribable to the studied effect.

Only small differences, having no relationship to differences in feeding, were recorded in the content of ammonia and urea in milk.

The consumption of feed mixtures depended on the output of milk by each cow. In conversion per kg of milk produced, the cows of the control group consumed 0.21 ± 0.019 kg of mixture and the cows in the experimental group 0.195 ± 0.021 kg. This shows that only a minimum difference existed in the consumption of concentrates per kg of milk produced. The low consumption of concentrates depended on the high production efficacy of the basic feed rations (10 - 11 kg of milk).

The following conclusion was derived from the study: - in cow nutrition part of the nitrogenous substances can be replaced by the tested form of synthetic nitrogenous substances, without a negative effect on performance, on milk composition and health condition. The urea - urea phosphate combination appeared to be unsuitable;

- the replacement can be successful when the content of N-compounds in the dry matter of the ration is lower than 13%;
- the feed mixtures in which extracted groats were replaced by synthetic N-compounds can be fed to cows with a performance up to 4 000 kg milk throughout lactation; the cows producing more milk can be given such mixtures only in the second half of lactation.

To express the actual nutritive value of the cow feed rations only by chemical analysis and by the feed values used, i.e. digestible nitrogen compounds and starch units, is an increasingly difficult task, on the basis of the existing findings. It has been demonstrated many times that the same content of nutrients in the ration is not always a guarantee of their equal production efficacy. It is a well-established fact that each error or drawback in this field under large-scale conditions of production with the group-housing system of production always entails economic losses.

This is the reason why the so-called model-optimized feed rations for cattle were put to use on an over-all national scale; these doses vary with production regions and were tested by research institutes as to their production efficacy and as to their nutrition parameters.

The new, presently introduced system of cattle nutrition management requires that model rations, i.e. their nutritional parameters, and the actual analytically determined nutrient content in feeds (analysed in regional agricultural laboratories) will be used for the calculation of a sufficiently exact nutritive value of feed rations which would secure the expected nutritional effect; this calculation would be based on an optimization model (Kolár 1978). The commented works were also used as a basis for improving the exactness of the standard requirement for optimization in which 29 criteria are respected, ten of which take into account not only the requirement but also the mutual relationships of the basic parameters of protein and energetic nutrition, such as crude to digestible protein, total protein to urea nitrogen, protein (or digestible protein) to energy and to energy concentration.

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TABLE 1

Average content of nitrogenous nutrients in pasture stand (in dry matter)
at graduated application rates of fertilizer nitrogen (n = 16)

Content of N-compounds	Fertilizer N rate, kg/ha				F test
	0	100	200	400	
protein	18.20	19.80	20.55	24.45	12.52 **/
albumen	14.20	15.30	15.30	17.59	10.31 **/
NPN	4.00	4.50	6.25	6.55	9.50 **/
soluble protein	5.86	6.95	8.92	12.86	21.24 **/
% of soluble protein	32.20	35.10	43.40	52.60	-

**/ P 0.01.

TABLE 2

Changes in the content of organic nutrients in pasture stand
at different fertilization rates (in dry matter) (%) (n=16)

Average content of	Fertilizer N rate, kg/ha				F test
	0	100	200	400	
fat	4.45	4.55	4.85	5.15	2.02
fibre	25.15	24.15	23.35	22.80	5.75 */
N-free extractive substances	42.45	41.75	38.65	36.10	20.78 **/
% proportion in glycide sum:					
cellulose	37.92	40.80	40.87	40.19	-
pentosans	21.65	23.07	23.35	22.26	-
lignin	17.33	15.74	14.33	13.23	-

*/ P 0.05

**/ P 0.01

TABLE 3

Average digestibility coefficients of organic nutrients
from pasture stand (n = 8) (as %)

Per-ha N-appl. rate, kg	Aver. organic nutrient digestibility coefficients				
	N-compounds	ether extract	fibre	N-free ex- tract. subst.	organic matter
0	67.25	38.62	75.10	74.90	72.25
100	68.68	44.28	77.09	74.24	72.77
200	71.48	52.15	78.46	70.89	73.06
400	76.49	56.07	78.76	68.67	73.07

TABLE 4
Nitrogen balance

Parameter	Fertilizer N application rate, kg/ha			
	0	100	200	400
N taken in, g	102.33	106.88	109.60	125.71
N excreted in feces, g	33.51	33.47	31.26	29.55
N digested, g	68.82	73.41	78.34	96.16
N excreted in urine, g	50.07	54.31	56.80	71.10
N retention $\pm$ g	+ 18.75	+ 19.10	+ 21.60	+ 25.06

TABLE 5
Protein and Energy Intake in Cow Feed Rations and Their Theoretical Production Efficacy
(n = 4)

Group - stand fertilized with: (N/ha, kg)	Aver. pure nutrients kg	kg d.m. taken in		total intake			PEQ= Dig.N. S.U.	Theoretical production efficacy, kg milk, by:	
		grass stand	potato flakes	N-compounds	Digestible N-c.	Starch units		Digestible N-compounds	Starch units
K - 0	586	12.5	0.65	2 087	1 392	7.73	180	16.00	16.0
I. - 100	582	12.5	0.54	2 258	1 515	7.71	196	17.99	16.0
II. - 200	591	12.5	1.48	2 610	1 810	7.76	233	22.38	16.0
III. - 400	588	12.5	0.35	3 052	2 294	7.74	296	29.85	16.0

TABLE 6
Nitrogen Balance and Nitrogen Utilization
(n = 4)

Group	K	I.	II.	III.
N appl. rate, kg per ha	0	100	200	400
N taken in with feed	333.92	361.28	417.60	488.32
N eliminated in faeces	111.23	118.79	127.99	121.35
N digested	222.69	242.49	289.61	366.97
N digested	65.32	67.12	69.35	75.15
N eliminated in urine	119.99	146.08	213.92	294.50
N eliminated in milk	89.60	89.96	84.45	78.79
N utilized for milk production	26.83	24.87	20.22	16.15
- of N taken in	40.23	37.06	29.16	21.47
- of N digested				
Balance	+ 8.52	+ 6.55	- 8.76	- 6.32

TABLE 7

The Content of the Soluble N-compound Fraction (% of N content) Determined
by Two-stage and One-stage Method in Some Selected Feeds

Sample	Two-stage method	One-stage method
Green forage:		
red clover	36.36	35.19
grass stand, pasture	30.20	30.12
grass stand, meadow	41.68	35.45
Hay:		
meadow hay	50.64	50.67
clover hay	34.40	37.72
lucerne hay	27.72	35.88
lucerne-grass hay	46.88	46.88
Haylage:		
lucerne	60.60	53.49
grass	64.64	70.06
clover	50.36	53.49
clover-grass	55.52	53.77
meadow stand	53.72	51.80
Silage:		
lucerne	60.85	59.72
oat	59.84	63.06
maize	69.25	70.08
Dried material:		
maize	33.36	34.20
mixed	37.57	40.92

TABLE 8Percentual Composition and Nutritive Value of Feed Mixtures

Feeds	Mixture composition in % -- effects			
	A	B	C	D
Maize	30	30	30	30
Barley	25	34	33	43
Groundnut groats	20	10	10	-
Fodder wheat flour	15	15	15	15
Wheat bran	7	7	7	7
Urea	-	1	0.5	2
Urea phosphate	-	-	1.5	-
Fodder limestone	1	1	1	1
Mineral mixture (MKP 3)	2	2	2	2
Dry matter	89.10	88.90	89.00	88.69
Nitrogen compounds	18.63	17.89	18.00	17.35 _x
Digestible N-compounds	14.72	13.68 _x	13.92 _x	13.10 _x
Starch units	70.29	68.21	69.00	69.96
Fibre	3.13	3.07	3.04	3.02
% share of urea in N-comp.	-	16.04	17.22	33.14

_x Coefficient 75% was used in the conversion of urea N to digestible N-compounds

TABLE 9Feed Mixture Consumption (kg) and Nutrient Consumption per kg of Milk Produced

Effect - feed mixtures	Mixture consumed per		Nutrients consumed per kg milk			
	kg of milk	kg FCM	d.m. g	N-comp. g	Digest. N-comp.g	Starch units
A	0.333	0.299	772	121	82	0.471
B	0.322	0.303	755	119	81	0.462
C	0.335	0.315	778	123	83	0.477
D	0.361	0.331	812	128	88	0.499

TABLE 10Milk Output and Composition

Effect	Output		Milk composition			
	milk kg	FCM	dry matter	solids- no-fat	fat	protein
A	16.74	18.04	12.85	8.33	4.52	3.26
B	17.21	18.39	12.95	8.52	4.43	3.32
C	16.83	17.81	12.86	8.45	4.41	3.39
D	16.39	17.61	12.78	8.23	4.55	3.36

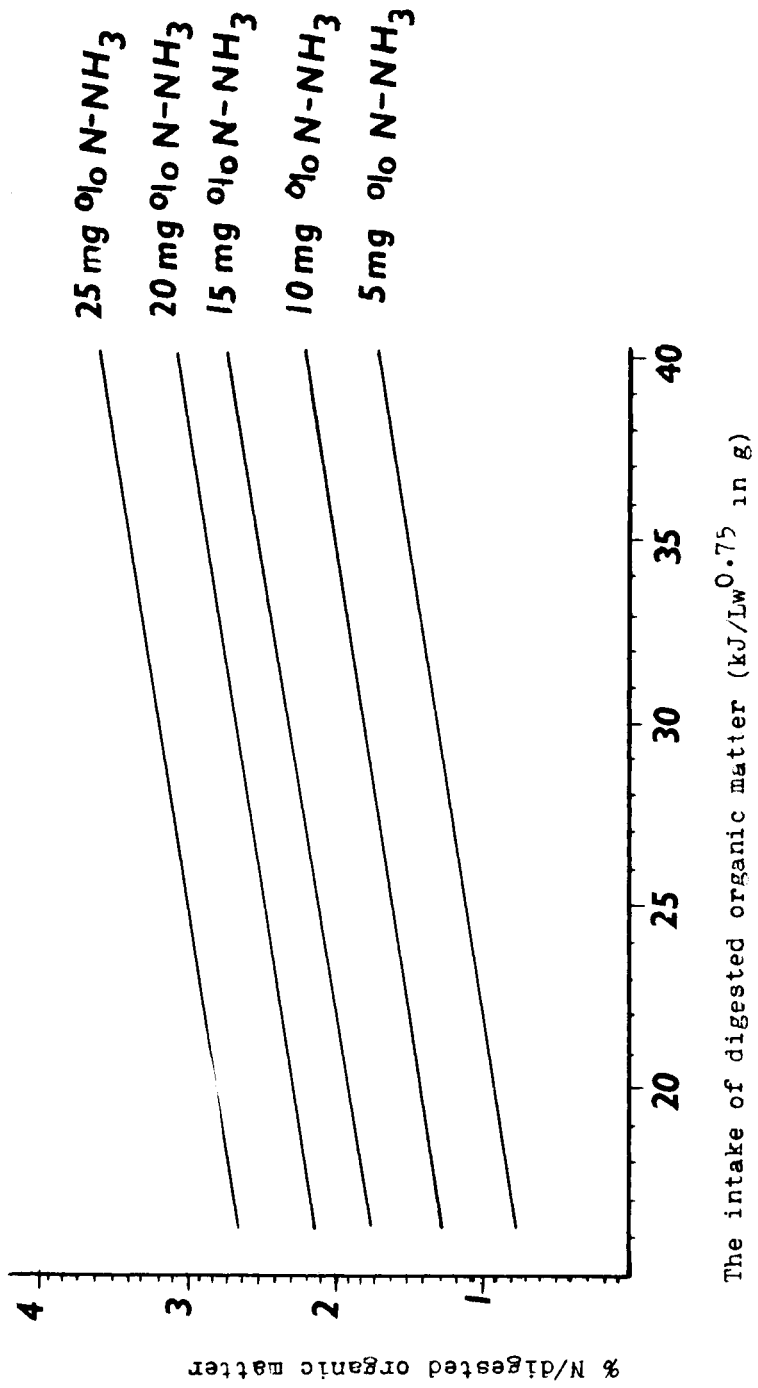
TABLE 11The Composition of Production Mixtures (%)

Components	In control group A	In test group B
Extr. soya groats	15	-
Wheat	40	55
Barley	22	19.5
Fodder wheat flour	15	20
Wheat bran	5	-
Urea	-	1.8
Urea phosphate	-	1
Mineral mixture (MKP 3)	3	2.7

TABLE 12Average Milk Output (for 305 lactation days) and Milk Composition

Parameters	In control group A	In test group B
milk output, kg	16.65 $\pm$ 1.05	16.20 $\pm$ 0.97
FCM output, kg	17.05	16.01
Content of dry matter %	12.53 $\pm$ 0.15	12.07 $\pm$ 0.29
fat %	4.28 $\pm$ 0.12	4.05 $\pm$ 0.18
protein %	2.95 $\pm$ 0.04	2.93 $\pm$ 0.12
NH ₂ mg%	1.05	1.10
urea mg%	51.14	48.65

Graph 1. The dependence of the percentage of nitrogen on the intake of digested organic matter $\text{kJ/Lw}^{0.75}$ in g and concentration of N NH_3 in rumen liquor



The Significance of Protein/Energy Relationships in the Practical Feeding of Dairy Cattle under Subtropical Conditions

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INTRODUCTION

Good utilization of the feed by ruminants depends on the supply of N for maximal fermentation in the rumen and the supply of amino acids in an amount and composition that is needed for maintenance and production. The supply of N and amino acids for the above purposes does not necessarily have to coincide with each other. Intensive breakdown of the feed in the rumen brings about an intensive synthesis of microbial protein. The percentage of amino nitrogen in microbial N, its digestibility and biological value are lower than the protein of plant sources that are fed to ruminants. Many research teams have tried to improve the protein supply by the use of different protein sources, pretreatments of the feed, and mainly by the correct ratio of available energy to protein in the ration (4, 11, 16, 18). In an extensive management system it is difficult to control the above factors but, as management becomes more intensive and the ration is planned for maximal utilization, their importance increases.

The following are described in this paper:

1. A nutritional survey of 33 dairy herds in Israel.
2. The influence of feed protein level on the performance of dairy cows.
3. Feed protein utilization by milking cows fed rations that differ in concentrate-roughage ratio.
4. Analysis of the above data in order to determine protein requirements for milk production.

EXPERIMENTS AND RESULTS

There are approximately 120,000 dairy cows in Israel, of which 62,000 are registered. All the cows are from the same genetic pool and are considered as Israel-Friesian cows. The average annual yield of registered cows was on the increase until 1978. In 1979 the average annual yield was 7,855 kg, with fat and protein contents of 3.27 and 3.0 per cent, respectively.

In 1977 a nutritional survey was carried out by Amir and Kroll (2) in 33 herds in order to determine the feeding management for high-yielding cows during the period between 40 and 120 days after calving. The survey was carried out in herds in which management is closely controlled. A whole ration was supplied with the help of a feed mixer wagon and it was possible to obtain accurate data on the amount and composition of the feed fed. The typical ingredients of the ration and their amounts are listed in Tables 1 and 2. Approximately 26 per cent of the ration's dry matter is fed as roughage. The main ingredients in the concentrate are corn and barley grains and soybean meal and cotton seed meal as main protein supplements. There is a tendency to use maximal amounts of local products such as cotton seed,

milk whey, poultry manure, etc. The average energetic value of the ration is 2.71 Mcal/kg DM of metabolic energy (ME).

NRC (1978) recommendations were used as the basis for the protein supply in the ration. Accordingly, it is acceptable to feed 16 per cent crude protein (CP) in the ration. The incorporation of low-protein byproducts in the ration (whey, sugar beet pulp, citrus pulp, etc.) demands the addition of feed that is high in protein. The average concentration of feed protein in the surveyed herds was 16.6 per cent (14.7 - 19.7 per cent). The statistical analysis of the data showed that the level of CP in the ration did not affect milk yield or milk fat percentage but did show a negative correlation with feed intake ($r = -0.40$, $P < 0.01$) and a positive correlation with feed utilization ($r = 0.31$, $P < 0.05$).

The small standard deviation of the average data on the amount of the ingredients in the ration shows that there is little difference among rations fed to the herds in Israel.

In 1978 an experiment was carried out in the herd of Kibbutz D'vir, on the effect of two levels of protein (15.5 per cent and 18 per cent CP) on the performance of cows up to 180 days after calving (3). The average annual milk yield in 1977 was 9,000 kg per cow. All the cows that calved were randomly assigned to one of the two treatments. The addition of protein was done by replacing some of the grains with soybean meal. The ration MD $\frac{*}{\text{kg}}$ was 2.75 Mcal ME/kg DM. The concentrate level in the ration was 70 per cent, which included 2 kg/day/cow cotton seeds, and 30 per cent roughage, mainly corn silage and 2 kg/hay/cow alfalfa hay. The crude fiber content was 14-15 per cent. Free choice feeding was offered to groups of 40 cows. Once every two weeks the milk was weighed and the fat and protein were analysed. Three times daily the cows were checked for heat and data were collected on their fertility and health conditions.

The data presented in Table 4 show that the addition of protein at a level higher than 16 per cent did not affect feed intake or milk production.

Fertility results are shown in Table 5. Cows on the high-protein level tended to be less fertile, requiring an increased number of inseminations per conception, and having a greater number of days open. Thirty-two per cent of the cows conceived from the first insemination in the low-protein level and 46 per cent in the high-protein level. The analysis of the fertility data according to the age of the cows (number of calvings) showed that as the age increased, fertility declined, mainly in cows fed the high-protein level (Fig. 3).

In an experiment that was carried out in our department by Amir *et al.* (1) cows were fed rations that differed in their concentrates-to-roughage ratio: 90:10, 70:30, 40:60. All treatments were supplied with protein in excess. In this situation the effect of the different protein-to-energy ratios on milk production could be checked. The cows were fed *ad lib.*, daily feed intake, milk production and body weight were recorded, and once a week milk composition was analysed.

Table 6 shows the group averages and the individual results of some extraordinary cows. The energy intake and milk production of cows fed the 70:30 ratio were higher in comparison with the cows on the 40:60 diet. The difference in CP intake (g/day) is much smaller and does not reflect the great difference in milk protein excretion between the two groups. The increase in roughage brought about, as expected, an increase in milk fat and in body weight loss after calving.

* / Meal ME of the diet per kg DM.

DISCUSSION

In analysing the results of the survey carried out on the 33 dairy herds, it was found that when the CP level in the ration ranged from 14.7 to 19.7 per cent there was a negative correlation between CP level and DM intake. These results were not found in the experiment carried out at Kibbutz D'vir (Table 4). In practical feeding, the idea that an increase in protein supply above a certain level may limit feed intake is not yet taken into consideration. During the first period after calving, the main limiting factor of milk production is the difficulty of consuming enough feed; it is therefore of importance to gather more information in this area. According to Polan *et al.* (15), feed intake drops as CP level increases above 12 - 13 per cent. Likewise, as feed NPN level increases, feed intake decreases. Others found (10) that CP levels higher than 16 per cent also improved feed intake. According to Clark and Davis (5), an increase in the level of ammonia that reaches the liver affects carbohydrate metabolism and there is a reduction in the amount of glucose entering the Krebs cycle. As a consequence, less protein is utilized and more energy is needed for detoxification of ammonia and its excretion as urea in the urine. The over-all result of excess amounts is less energy available for production. Tyrell *et al.* (17) state that "Intake of protein in excess of the amount required by lactating and dry cows, resulted in decreased energy balance at a given level of energy input". These findings emphasize that even during the first period after calving, the level of diet CP should be minimal. Feed management and the sources of diet protein should also be planned so that a minimal amount of ammonia will escape from the rumen into the blood.

This point was discussed in depth by Oldham (14) who claimed that the source of dietary protein can substantially influence milk yield early in lactation. He also distinguished between responses due to protein effects on energy utilization and protein effects brought about through change in amino acid supply to the tissue. However, there is a lack of information about high-yielding cows.

Today a great deal of work is carried out on the planning of protein supply for ruminants in order to satisfy the microbial needs for maximal fermentation and the requirements of the host animal for the amino acids needed for intensive production (4,11,16,18). All these ideas have certain common assumptions:

1. Protein supplementation in the diet must take into consideration the amount of over-all energy available
2. Different estimations of the contribution of the microbial protein and of the undegraded feed protein for milk production.

In Fig. 1 we tried to combine these elements by describing protein requirements as intestinal amino nitrogen (IA-N) per ME (g/Mcal), as a function of milk production. Evaluation of nitrogen requirements were determined according to Roy *et al.* (16), and of energy according to NRC (1978). IA-N requirements were calculated for a 550-kg cow: maintenance requirements of 15.11 Mcal ME, 461 g Cp and milk composition (/kg) of 32 g fat, 32 g protein (Nc6.38) and 1.11 Mcal ME. The IA-n/ME requirements may be calculated as a range between minimal requirements - when all the nitrogen is from undegraded feed protein (0.70 digestibility and 0.90 biological value), and maximal requirements - when all nitrogen is from microbial sources (0.80 amino-N, 0.70 digestibility and 0.75 biological value). Crude protein concentration in the ration can be calculated when there is additional information on the metabolism of diet proteins in the rumen (the rate of breakdown and ammonia loss to the blood). Accordingly, when the rate of microbial protein synthesis is 5 g/Mcal ME (16), and 70 per cent of IA-N is of microbial

origin, the cow will not be capable of producing more than 20 kg milk per day (Fig. 1). The addition of protein to the ration may bring about an excess of ammonia production which may limit the energy supply. It seems that during the first period after calving to peak lactation, the addition of low degradability protein to the ration should be considered.

The percentage of CP in the ration DM was not found to be a good parameter of milk production, especially when comparing rations differing in their MD (Table 6). However, a high correlation was found (Figure 2) between the amount of dairy milk protein (Y) and daily IA-N/ME requirements (X), according to the following equation:

$$Y = 0.580X - 345, r = 0.806 \quad (P < 0.01)$$

IA-N requirements in the above equation were determined when 70 per cent of IA-N was of microbial source. The conversion efficiency of IA-N to milk nitrogen is 58 per cent. As the relative amount of undegraded feed nitrogen in IA-N increases, the production efficiency increases.

In the present work (Table 5, Fig. 3) a tendency of low fertility was shown when cows were fed a ration high in protein. These results are in accordance with previous trials (7,8,9). All the work done in the past with milking cows was not aimed at probing the fertility problem, and any such results that were observed were a by-product of experiments or surveys done on commercial herds. It might be that excess protein in the diet stimulates a negative energy balance (14) which may interfere with the process needed for pregnancy development. However, most of the loss in body weight is during the first and second months after calving; it is, therefore, difficult to assume that this will be effective three to four months later, when cows are gaining weight.

In an experiment carried out in our department (6), rats were used in concurrent lactation in order to study the effect of protein level on fertility. It was found that an increase in the ration protein from 11 to 32 per cent increased the loss of body fat. Milk production was greatest when the rats were fed the 16 per cent CP diet. An increase in feed protein brought about a decrease in fertility (number of fetuses per rat and their size at 14 days of pregnancy, duration of pregnancy, and number of fetuses at birth) only when soybean meal was added. However, when casein or isolated soy protein was added, no negative effect on fertility was observed. Similarly a negative effect was achieved when the non-protein residue of the soybean meal (molasses) was added to the diet. Different substances in forage, including coumestans and isoflavones, usually referred to as plant estrogens, have reproductive effects in animals. As a rule protein levels are increased by adding soybean meal which is known (12) to contain at least three plant estrogens: genistein, daidzein and coumestrol. In the future we plan to run some experiments on dairy cows to study the effect of feeding soybean meal in comparison to other protein sources on their fertility.

CONCLUSIONS

1. This work expresses the need to use a precise amount of protein in the diet, especially during the first lactation period, when excess protein may limit the efficient utilization of the available energy consumed.
2. The efficiency of feed protein utilization for milk production is affected by the ratio between microbial IA-N and undegraded feed protein IA-N.

At the beginning of lactation, when limitations in feed intake could bring about a lack in protein, it is recommended to supply a low degradable protein in the diet.

3. It could be that the use of large amounts of soybean meal in dairy cattle feed will have a negative effect on their fertility.

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TABLE 1Composition of feeds (% of dry matter) supplied to a
group of cows at peak lactation

(from Amir and Kroll, 1980)

Ingredients	Dry matter	Crude protein	Crude fibre
Concentrates	87.1	17.0	5.6
Quasiconcentrates	89.4	19.7	18.0
Liquid whey	4.5	13.0	-
Miscellaneous	88.1	18.9	32.1
Silage	27.2	8.7	29.4
Hay	89.0	14.7	31.8
Green fodder	15.4	17.1	21.1

Quasiconcentrates: whole cottonseeds, beet pulp, citrus peels.

Miscellaneous: cotton by-products, poultry litter.

Silage: mainly corn and wheat silage.

Hay: mainly vetch hay.

Green fodder: mainly clover and ryegrass.

TABLE 2Ingredients supplied in rations of cows at peak lactation

(from Amir and Kroll, 1980)

Ingredients	Dry matter (kg/d)		% in total dry matter	
	Mean	S.D.	Mean	S.D.
Concentrates	11.35	1.66	53.89	7.96
Quasiconcentrates	3.13	1.48	14.76	6.89
Liquid whey	0.65	1.09	3.08	5.17
Miscellaneous	0.45	0.86	2.16	4.19
Roughage ^{1/}	5.51	1.20	26.12	5.24
Total dry matter intake	21.20	0.01	100.00	-

^{1/} Silage, 2.56 kg; 2.33 kg; green fodder, 0.62 kg.

TABLE 3Feed intake and milk yield of cows from 40 to 110 days
after calving

(from Amir and Kroll, 1980)

	Mean	S.D.	Minimum	Maximum
DM intake (kg/d)	21.2	1.01	22.3	18.6
ME intake (Mcal/d)	57.4	3.05	56.0	65.6
CP in ration (%)	16.6	1.09	14.7	19.7
Milk yield (kg/d)	36.9	3.23	30.4	43.9
Milk fat (%)	2.87	0.32	2.18	3.41
Milk protein (%)	3.00			
Milk protein (g/d)	1 107			
IA-N/ME requirement (g/Mcal) <u>1/</u>	7.55			
Intestinal N-amino x 6.25 requirement (g/d)	2 708			

1/ Calculated according to Fig. 1, assuming that 70 per cent
of intestinal amino-N is of microbial source.

TABLE 4

Feed intake, milk yield and composition of cows fed low (LP) or high (HP) crude protein rations during 180 days after calving

Days after calving:				90			180		
Treatment:	LP	HP	S.E.	LP	HP	S.E.	LP	HP	S.E.
No. of cows	54	45		47	41		24	26	
Dry matter intake (kg/d)	19.3	19.2	0.26	19.6	19.5	0.05	19.4	19.8	0.30
Calculated ME intake (Mcal/d)	53.1	52.8		53.9	53.6		53.4	54.5	
Ration CP level (%)	16.3	18.3	0.17	16.0	18.4	0.21	16.0	18.5	0.21
CP intake (g/d)	3 146	3 514		3 136	3 588		3 104	3 663	
Milk yield (g/d)	36.2	35.9	0.66	32.9	34.2	0.67	26.1	26.1	0.83
Milk fat (%)	2.72	2.94	0.06	2.58	2.74	0.05	2.73	2.97	0.07
Milk protein (%)	3.27	3.28	0.04	3.36	3.37	0.04	3.60	3.63	0.06
(g/d)	1 184	1 177		1 105	1 152		940	947	
4% FMC (kg/d)	29.1	30.1	0.59	25.8	27.6		21.1	21.9	0.67
Intestinal amino-Nx625 requirement 1/ (g/d)	2 489	2 475		2 459	2 479		2 319	2 367	
(% in IM)	12.9	12.9		12.6	12.7		11.9	11.9	

1/ Calculated according to Fig.1, assuming that 70 per cent of IA-N is of microbial origin.

TABLE 5

The effect of diet protein level (low = LP or high = HP) on the fertility of cows

Treatment	No. of cows	Services per conception	% conception by first insemination	Cows pregnant	Days open
LP	64	1.81	32	48(75.0%)	92
HP	56	2.39	46	43(76.8%)	114

Table 6
Energy and Protein Intake and Milk Yield and Composition of Cows Fed Diets Differing in Their
Concentrate-to roughage Ratios (from Amir et al.)

	Individual cows 3-6 weeks post partum						Group average 5-8 weeks post partum		
	90:10	70:30	45:1	39:3	37:7	30:6	90:10	70:30	40:60
Concentrate:roughage ratio:									
Milk yield (kg/d)	48.9	45.1	39.3	37.7	30.6		34.6	35.9	30.2
Milk fat (%)	1.82	3.45	3.27	2.90	4.43		2.49	2.83	3.29
Milk protein (%)	3.19	2.86	2.93	2.63	2.65		3.28	3.15	2.90
(g/d)									
BW change (g/d)	1561	1291	1151	991	810		1135	1131	876
DM intake (kg/d)	-610	-790	-1100	-930	-2560		-41	-74	-352
ME intake (Mcal/d)	19.5	19.4	18.8	18.5	13.1		17.8	19.6	17.6
Total ME for production ^{1/} (Mcal/d)	54.55	50.78	49.20	43.01	30.78		49.42	50.11	42.50
CP concentration in DM (%)	59.60	57.30	58.26	50.70	51.87		50.00	50.72	45.40
CP intake (g/d)	20.8	18.3	17.4	21.1	20.9		18.1	17.1	17.7
Intestinal N-amino ₂ requirement (g/d)	4055	3542	3268	3912	2734		3223	3357	3123
	2980	2829	2804	2408	2318		2328	2377	2029

^{1/} Includes contribution of body reserves. Weight loss was converted to ME according to NRC (1978).

^{2/} Calculated according to Fig. 1, assuming 70 per cent of IA-N is of microbial origin.

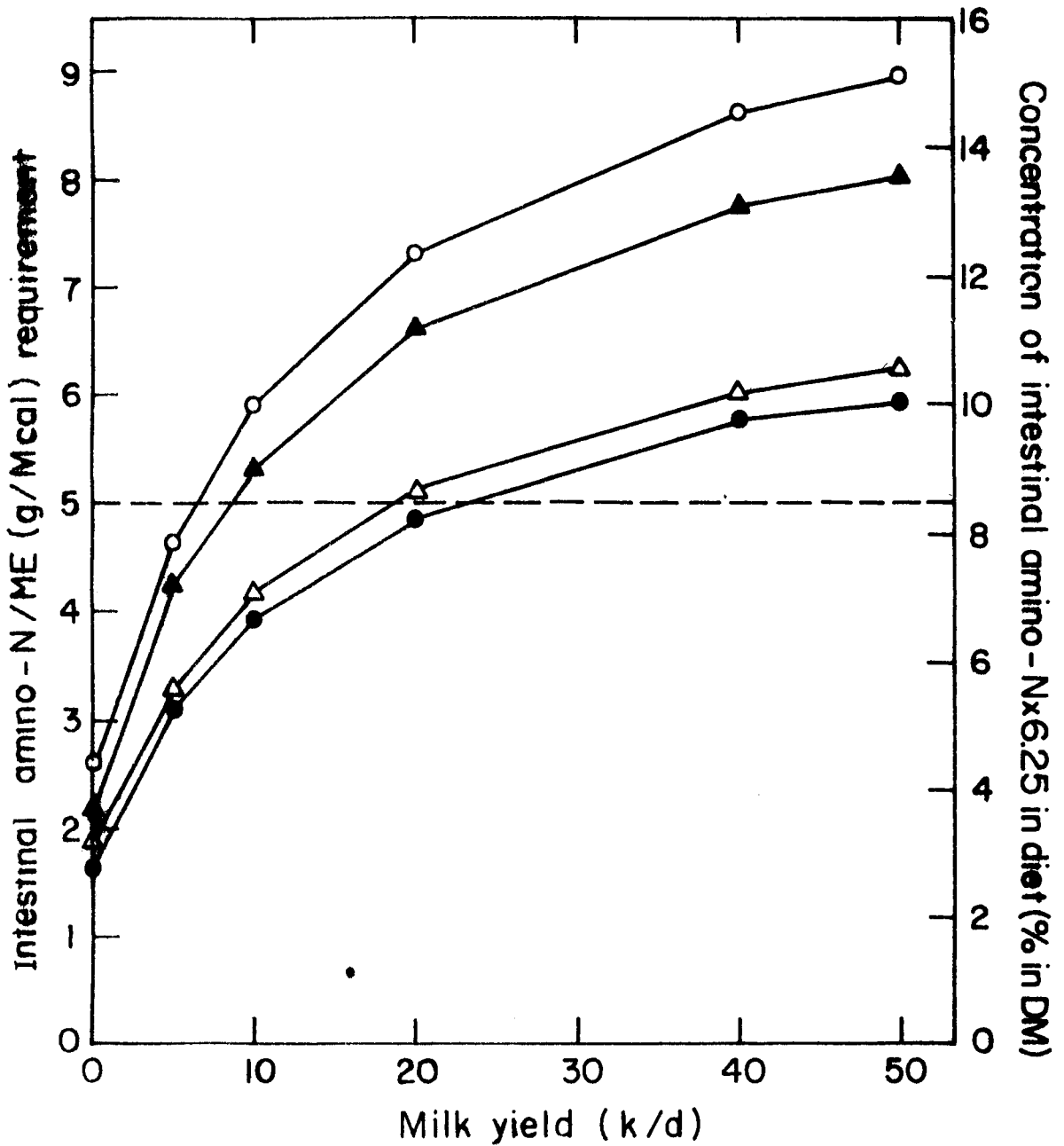


Fig.1 Intestinal Amino-N/ME (g/Mcal) requirement for milk production (kg/d) when 0 (●), 70 (▲) or 100 (○) per cent is of microbial origin.
 - Microbial IA-N when it composes 70 per cent of total IA-N.

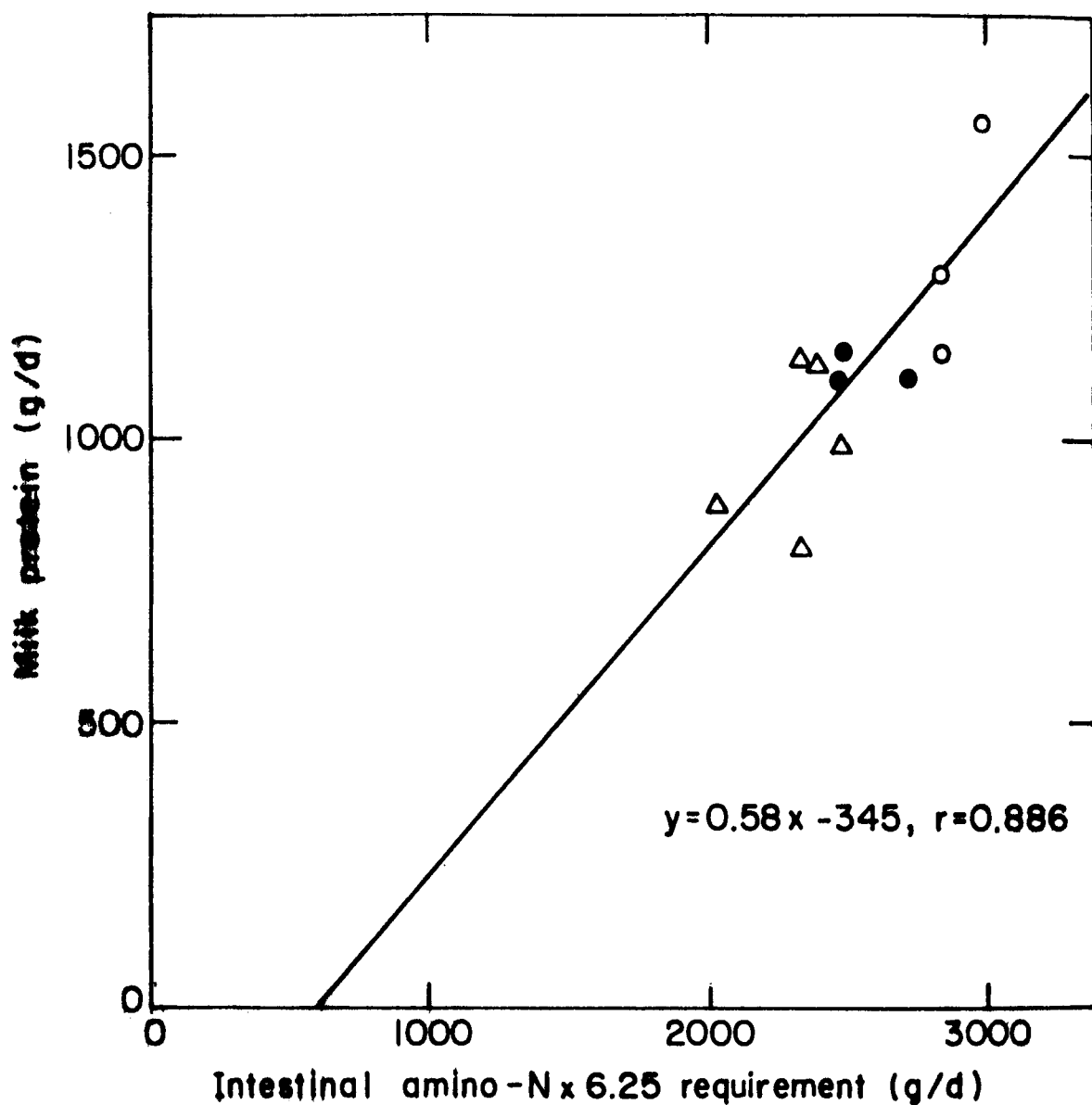


Fig.2 Milk protein (g/d) as a function of intestinal amino-N requirements, calculated according to Fig.1, in the survey and in the Kibbutz D'vir experiment (●) and in Table 6; individual cows -△, group averages ○.

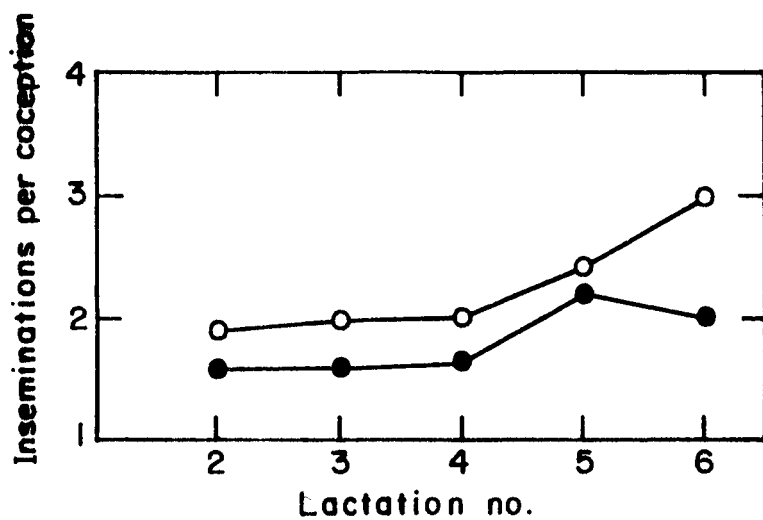


Fig.3 The effect of the age of the cow (lactation number) and feed protein level (low protein - ●, high protein - ○), on the number of inseminations needed per conception.

Significance of Protein/Energy Relationships in the Practical Feeding of Dairy Cattle Under the Climatic Conditions of Northern Europe

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In Finland, as well as in the other Nordic countries, the possibilities of producing plants that can be used directly by man are rather restricted. This is reflected by the fact that of the 100 crops on which mankind depends for its food supply, only about 10 can be cultivated in Finnish latitudes. Owing to this northern location, animal husbandry plays a dominant role in farming. Farm animals are used to convert products that cannot be used by man into high-quality food - milk, meat and eggs.

Ruminants, especially cattle, have an important position in the agriculture of the Nordic countries. In Iceland, however, the role of cattle is small compared with that of sheep. In Norway, too, sheep and goats occupy an important position. Denmark has far more cattle than any other Nordic country. In Sweden and Finland the cattle numbers are in the same order of magnitude. Reindeer are almost equally abundant in Finland, Norway and Sweden.

In all the Nordic countries, except Iceland, the number of cattle has decreased since the beginning of the 1960's, although the decrease has been less pronounced in the 1970's.

The contribution of animal products to the income of Finnish agriculture is over 80%. This value has remained of the same order for several decades. The most important product is milk. The income from cattle alone, i.e. from milk and beef, accounts for over 60% of the agricultural income which illustrates the importance of cattle in Finnish farming.

SOME GENERAL TRENDS IN CATTLE FARMING

The present number of dairy cows in Finland is about 700 000. The total annual yield is about 3 100 million litres. Milk production decreased at the beginning of the 1970's but has increased again in recent years. This, in spite of the fact that the number of cows has decreased during this time by 5 000 - 10 000 annually. Although some factors of uncertainty are always involved in long-term assessments of production, it seems that no sharp decline in milk production in Finland is to be expected in the future.

According to the linear trend shown by the production of the years 1960-78, the mean milk yield per cow may be estimated to rise by almost 80 kg a year. Thus, by 1990 the mean milk yield should be over 5 300 litres a year. It would be perfectly possible to achieve this, since the present production of the certified cows already exceeds this value, and we even have a number of cows whose annual milk yield is well over 10 000 kilos. It should, however, be mentioned here that only 1/3 of the dairy cows in Finland are registered with the Milk Recording Society. In 1979 the average milk yield of these registered cows was about 5 800 kg FMC, whereas the average for all cows was about 1 000 kg less.

The continuous increase in milk production is due both to an improvement in the animal stocks and to better feeding.

The consumption of milk in Finland, on the other hand, is expected to decrease in the 1980's. In 1979 the consumption of milk and liquid milk products in our country amounted to 290 litres per person. The corresponding value for butter was almost 13 kilos and that for cheese was about 7 kilos.

In both Finland and the other Nordic countries there is a close connection between the production of milk and beef. About 80% of the domestic beef production in Finland originates from dairy farms. The number of dairy cows thus largely determines the level of beef production. At present the annual consumption of beef is 24 - 25 kilos per person, but it is expected to rise in the 1980's.

During the 1970's the mean carcass weight has risen by a little less than 4 kg a year. If this trend continued, the mean carcass weight in 1985 would be 190 kg and in 1990 210 kg. However, the increase in weight in the 1970's was partly caused by a change to a different breed of cattle, and the future increase in weight cannot be expected to be as sizeable as in the past.

One way of satisfying the domestic demand for beef would be to breed more beef cattle. This would, of course, be the simplest alternative, but unfortunately the conditions in our latitudes are such that it would not always be very rewording economically, even if subsidized by the state. To keep a cow for a whole year in order to obtain one calf obviously cannot be an economic proposition in a country where the period of indoor feeding is 7 to 8 months.

FEED RESOURCES

In all the Nordic countries the improvement of the yield of the dairy cows has necessitated an increase in the use of concentrates. The average ration fed to dairy cows in Finland contains about 60% roughage and 40% concentrates and the ratio of roughage to concentrate is roughly the same in Norway and Denmark. The proportion of concentrates in the ration is slightly larger in Sweden, or about 50%. In Iceland, on the other hand, the proportion of concentrates in cattle feed is only 20-30%.

The trends in feed production have been the same in all the Nordic countries, except Iceland. The land under cereals and the crops of feed grains have increased, while the cultivation of herbage has decreased. In Iceland almost all the agricultural land is used for pasturage and fodder. Over-production of feed grain has occurred, especially in Denmark and Sweden, and grain is exported from those countries. In contrast, Norway and Iceland have to import grain concentrates.

The production of the domestic animals in the Nordic countries has long been based, at least partly, on imported protein. In recent years the question of the protein required for feeding domestic animals has been the focus of attention, particularly in Finland. Occasional difficulties experienced in procuring imported feeds and sharp fluctuations in their prices have made it desirable to explore all possibilities in respect of protein.

A statistical evaluation of the production of animal feed in Finland shows that our country has been almost self-sufficient in respect of energy for several decades, producing up to 97% of the amount required. Over the years, changes have occurred in the composition of the imported feeds. Apart from some years in which the harvest has been poor, there has been a general tendency to import

increasingly protein-rich feeds. Under normal circumstances the feed imported from abroad consists chiefly of protein - and protein of high quality.

The protein and energy used by our domestic animals are derived from the following sources:

	Digestible crude protein (DCP)	Feed units (FU)
Agriculture	74%	84%
Industry	10%	7%
Imported feeds	16%	9%

This distribution may change by some percentage units from one year to another, but the size classes remain the same.

Our domestic animals thus obtain the bulk of their protein, or about $\frac{3}{4}$, from agriculture. The remaining quarter is derived from domestic raw material, such as industrial by-products or imported from abroad. The two last-mentioned sources provide chiefly high-quality protein. The protein originating from industry includes milk, meat and fish protein. The greater part of the imported protein consists of soya, fish meal, fish and rejected fish. The contribution of imported protein to the protein consumption of Finnish dairy cows is about 5%.

The feeds produced in Finland and used for dairy cows are generally rather bulky. Because of this, the cows, especially those with high milk yields, cannot eat enough of them to obtain sufficient energy and protein. It is particularly difficult to meet the nutrient requirements of the animals with domestic fodder at times of peak production, i.e. when the daily milk yield exceeds 30 kg. A deficiency of energy and protein during this phase of production reduces the milk yield and decreases the protein and often also the fat content of the milk. It also makes the animal more susceptible to disorders of the metabolism and impaired fertility.

ROUGHAGE

The 1970's were a turning point in the feeding of dairy cattle. During this decade there was a strong increase in the preparation and use of silage, mainly at the expense of hay. In 1978 the registered cows in Finland received as many feed units from silage as from hay. Both types of fodder contributed about 650 FU per cows. By 1979 the contribution of silage exceeded that of hay.

In spite of this sharp rise in the use of silage, a further increase is still perfectly possible. Even with the registered cattle the average daily ration of silage is only 17 - 18 kg per cow. Research and practical experience have shown that in silage - based diets at least twice this amount can easily be given.

Our dependence on imported protein in dairy cow feeding can be decreased by using silage. A silage - based diet containing only 2 - 3 kg of hay per day can provide sufficient protein for a daily milk yield of up to 25 - 30 kg. The energy provided by silage is sufficient for a daily milk yield of about 10 kg. When the daily milk yield exceeds 30 kg, sufficient energy can be provided with a mixture of barley and oats, but there will be a deficiency of protein. This protein deficit could be eliminated by increasing the protein content of our silage from its present level of 150 - 160 g DCP/FU to 180 g DCP/FU, which would in fact be feasible.

For example, the protein content of the herbage could be increased by harvesting the grass at an earlier stage of development. However, this would lead to a decline in the yield and a rise in the cost of harvesting. Another way to increase the protein content of the herbage would be to increase the cultivation of leguminous plants, mainly red clover. The application of fertilizers to grassland has decreased as a result of the increase in the price of fertilizers, especially nitrogen fertilizers.

There has been a continuous decrease in the use of hay in dairy cow feeding, and this trend will continue in the present decade. The protein content of hay has shown little change during the 1970's. At the moment it averages 100 - 110 DCP/FU.

The main aim as regards hay feeding is to increase its concentration and protein content. This could be achieved by the introduction of new harvesting and drying methods. The barn-drying method, in particular, allows the preparation of high-quality hay.

Pasturage has remained at about 850 FU per year, but its proportion in the feed has fallen. Its contribution should be kept as big as possible, since pasture provides the cheapest feed units. The use of concentrate as a supplement to pasturage should be increased as the level of production rises, since the cow cannot obtain more energy from grazing, even on good pasture, than that needed for a daily milk yield of 20 - 22 kg.

The use of straw for feeding has been slight. In the registered dairy cattle the proportion of the energy obtained from straw is a little less than 0.5% of the total.

However, the possibility of increasing the use of straw has improved with the introduction of new methods of treatment - with sodium hydroxide and ammonia. The energy concentration of the treated straw approaches that of hay, and the ammonia treatment raises the DCP content. The spread of the sodium hydroxide treatment has been hampered by the high cost of the equipment, but this disadvantage can be reduced by sharing the machine among several farms. The plastic required in the ammonia treatment is also expensive. The treated straw can best be used as roughage in high-concentrate diets for beef cattle and as a substitute for hay in silage-based diets for dairy cows.

CONCENTRATES

The extent to which grain, barley and oats, is cultivated for animal feeding depends mainly on the extent of the animal production. As over-production of dairy products must be avoided and the number of cows is likely to decrease slightly, no increase in the consumption of grain concentrates can be expected at present. However, the proportion of grain concentrates in the ration may increase, mainly at the expense of herbage. This is indicated by, for instance, the expanded capacity of the cattle feed industry and the growing use of commercial feeds for cattle.

The use of commercial mixtures in cattle feeding has increased sharply in the last few years. There are several reasons for this. One of them is the concentration of cattle farming in eastern and northern Finland where it is more profitable to have the land under grass than under cereals, and the need for commercial feeds is greater. Another reason is a change in the structure of animal husbandry. In many farms an increase in the number of cattle has been accompanied by intensified cultivation of pasture herbage, so that grain cultivation has decreased and there has been a shift to commercial mixtures. By

using commercial feeds it is possible to avoid fluctuations in the harvest due to the uncertainty of grain cultivation and consequent irregularities in cattle feeding. Further reasons for the increase in the use of commercial feeds are their low price in comparison with the cost of on-farm production of concentrates and the fact that they are easy to use. The exceptionally low prices of commercial feeds are due to competition between the factories that produce them.

Since commercial cattle feeds are used in much bigger quantities in the other Nordic countries, it seems very probable that their use in Finnish cattle feeding will continue to increase. The raw materials of the feeds are domestic grain and a partly Finnish, partly foreign protein supplement. In 1978 imported raw material, mainly soya and fish-meal, composed 35% of the protein in the feeds. The chief sources of domestic protein were skim-milk powder, rape seed meal, and the by-products of the milling industry.

The industrial production of cattle feed can be maintained only if there is a sufficient supply of raw material. It would be desirable to increase the use of domestic protein sources as far as economically and technically possible. The import of the raw material for the feeds has grown more slowly than the industrial production of cattle feeds. One of the main reasons for this has been the expansion in the domestic production of oilseeds. The area under oilseeds has increased from 7 000 hectares in 1970 to 55 000 hectares in 1980, and it is planned to increase it still further. If the soya meal used at present in the feeds was replaced completely with domestic rape seed meal, the area under oilseeds would have to be increased to almost 100 000 ha, but it would then be necessary to export vegetable oil.

Self-sufficiency in respect of the protein used in cattle feeding might be achieved by increasing the use of urea. The use of foreign plant protein could be decreased to some extent by growing more peas and using these in the cattle feeds. On the other hand, the fairly small proportion of animal protein, mainly fish meal, used in the feeds will probably still have to be largely imported.

OTHER FEEDS

The use of beet tops as feed will probably decrease somewhat as the production of sugar beet becomes restricted to a decreasing number of farms. Recently, there has been much talk of the cultivation of root crops and cabbage as feed for domestic animals. However, in spite of good harvests their use seems to be decreasing rather than increasing. The reasons for this are the large amount of labour involved, the expense of the special machines required and the difficult storage.

PROTEIN/ENERGY RELATIONSHIP IN DAIRY COW FEEDING

According to the norms in Finland, the protein/energy relationship required for maintenance in dairy cattle feeds is 84 g DCP/FU (= 6.5 g DCP/MJ). The protein needed per kg FCM is 57 g DCP and the corresponding energy requirement is 0.37 FU. When the milk production is 10 kg FCM/day, the protein/energy relationship in the whole ration should be 106 g DCP/FU (= 8 g DCP/MJ), whereas at the level of 30 kg FCM/day it should be 136 g DCP/FU (= 10 - 11 g DCP/MJ). These values are about the same as the norms for the other Nordic countries.

In practice the cows are not always fed according to the norms. Both the protein/energy relationships of the ration and the concentration level of the feeding vary.

The composition of the ration for dairy cows, the supply of protein and energy and the relationship between the two have been recorded at the experimental farm of the University of Helsinki during the years 1955-1978. The number of cows during this period averaged 62 (ranging from 50 to 72) and the milk production averaged 5 776 kg FCM/year (ranging from 4 686 to 6 563 kg). The feeding has been quite intensive, both the energy and protein supply being higher than the norm during the whole period.

The protein/energy relationships of the ration and the milk production level have changed over the years. In the 1950's the ration contained 150 - 160 g DCP/FU (= 12 g DCP/MJ). In the 1960's, when imported protein (soya) played an important role in the feeding of cows, the protein/energy relationship was as high as 160 - 180 g DCP/FU (= 13 g DCP/MJ). In the 1970's the import protein was reduced, but at the same time the use of grass silage with a high protein content increased in Finland. The protein/energy relationship in the ration of dairy cows in the 1970's was 110 - 150 g DCP/MJ).

Although the protein/energy relationship in the ration diminished, the milk production of the cows increased rather than decreased. The average annual milk yields were as follows: in the 1950's 5 004 kg FCM, in the 1960's 5 880 kg and in the 1970's 6 090 kg. The increase in the milk production level during the test period 1955-1978 has thus been marked. The role of protein/energy relationship in the ration is very difficult to explain.

The changes in dairy cow feeding at the experimental farm are similar to those occurring in the whole country, especially among the cattle registered with the Milk Recording Society. In 1979 the protein/energy relationship in the feeds of the registered cows averaged 130 g DCP/FU (= 10 g DCP/MJ).

Cows have a certain genetically determined capacity for milk production and the aim in dairy cattle feeding should be to use this capacity in the most expedient and economical way. Although full advantage has not yet been taken of the capacity for production in Finland, feeding statistics indicate that over-feeding of cattle is fairly common. The reason for this situation lies in the fact that sufficient attention has not been paid to the current level of the milk yield and the demands exerted by this yield on the feed and the composition of the feed. If feeding is to conform with the nutrient requirements, the quality of the feed and its components should also be known, and the amount of the ration should be correct. In practice the people responsible for cattle feeding can easily obtain information on the nutrient requirements of the cow, and computerized planning of feeding and the advisory services available have increased the number of feed analyses performed in Finland. In contrast, the measuring of the ration is still often very inexact. In future this last-mentioned point should receive more attention from the advisory services.

The Significance of Using Special Protein in Early Lactation (Also with Regard to the Fertility of the Cow)

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INTRODUCTION

The bacterial transformations in the rumen include an extensive degradation of feed proteins (FP) and an energy-dependent bacterial protein (BP) synthesis. Therefore the cow has two protein sources at the intestine to cover the amino acid requirements, the BP and the undegraded part of the feed protein (UDP). Extensive knowledge about the degradation of protein and the BP-synthesis is necessary for a critical examination of the protein supply of the host and for describing the possible applications and limits of special proteins.

Bacterial protein synthesis

The BP-synthesis depends on an adequate supply with degradable protein as a nitrogen source and on the energy available for the bacteria.

Various workers have shown, that 3 - 8 mg of NH_3 in 100 ml of rumen fluid are sufficient for an optimal BP-synthesis (Buttery 1976, Hagemeister *et al.* 1980, Kaufmann 1979, Roffler *et al.* 1976, Slyter *et al.* 1979) especially if one considers the high affinity of glutamine synthetase for NH_3 and the buffering effect of the labile N-reserves (alanine, glycine), which can be used when NH_3 concentrate drops (Erfe *et al.* 1977). The relatively low demand for amino acids, resp. peptides are under normal feeding conditions also covered (Maeng *et al.* 1976, Maeng and Baldwin 1976).

Provided a sufficient nitrogen supply, the BP synthesis depends on the energy available for the bacteria. Under normal feeding conditions in mixed rations about 22 g of B are synthesised per 100 g apparently fermented organic matter (Brandt 1979, Hagemeister and Kaufmann, 1974, Hagemeister *et al.* 1976, 1980, Hvelplund and Møller 1978, 1980, Kaufmann 1976, 1979, Løpping 1979, Mühlbach and Kaufmann 1979, Rohr *et al.* 1979, Tamminga *et al.* 1979). Assuming that about 60 - 65% of the digestible O.M. are fermented in the rumen, about 15 g of BP are synthesised per 100 SE or about 8.2 g BP per MJ ME. Only in extreme rations either high in roughage or high in concentrates a lower rate of synthesis could be established in vitro as well as in vivo experiments (Fig. 1) (Hvelplund and Møller 1978, Løpping 1980, Russell and Dombrowski 1980, Russel and Baldwin 1979, Russel *et al.* 1979, Offer *et al.* 1975, 1978, Chamberlain and Thomas 1979, Oldham *et al.* 1977). Calculating with the intestinal protein requirements of Kaufmann (1979) (55.6 g c.p. per kg milk + 26 g endogenous c.p. per kg D.M. intake + 110 g c.p. losses in urine) and the energy feeding standards (275 SE/kg FCM, 3000 SE maintenance) the BP (20% nucleic-acids) covers 60-100% of the c.p. requirement (Fig. 2).

In high-yielding dairy cows, where the energy requirements are often not covered, the reduced BP-synthesis leads to a lower supply of BP according to the c.p. requirements at the intestine.

Feed protein transformations

Looking at the transformations of FP in the rumen, our own results with cows fitted with re-entrant cannula at the duodenum suggest a mean degradation rate of mixed feed proteins of about 70% (Table 1). For directly cut silages higher values are reported (> 90%), e.g. from Hvelplund and Møller (1980). This can be attributed to the relatively high content of NPN in these silages.

Possible influences of high feed intake on lower degradation rates are discussed but results up to now are contradictory (Tammenga 1978, Tammenga *et al.* 1979, Rohr *et al.* 1979).

If degradation rates measured in sheep can be used for cows, too, remains to be cleared. Using cows, we can calculate with a mean degradation rate of about 70% for proteins in mixed rations. This means, that even for high-yielding cows receiving rations with about 600 SE (~11 ME ME) per kg IM a maximum of 13% c.p. can be used without NH_3 losses in the forestomachs because the degraded part (70% of 130 g = 91 g just covers the requirements of the bacteria (600 SE $\times$ 0.15 g BP = 90 g BP). According to our feeding standards (Kaufmann 1979), however, 13% are only sufficient for a milk production of about 18 - 20 kg of milk. With higher milk yields the cow needs more protein at the duodenum, which can only be supplied by UDP. Fig. 3 shows the additional UDP requirement (straight line) and the resp. FP requirements which differ according to degradation rate. The crossed area shows the unavoidable NH_3 losses in the forestomachs, if the requirement of the host are covered by FP with degradation rates of 70%, resp. 40%. This NH_3 surplus is absorbed and must be detoxicated in the liver and hence excreted in the urine. An increasing load of the liver and higher blood and milk urea contents with increasing milk yields are the consequences of this situation (Erbersdobler *et al.* 1979).

Energy deficit

The high energy requirements for cows in early lactation are often not covered. This lack in energy leads to a smaller BP synthesis and hence to a lack in protein, too, and to an additional excess of NH_3 (Fig. 4). The portion of the total urea synthesis deriving from excess of rumen ammonia detoxication in the liver will increase under these conditions to 50% and more (Fig. 5). Considering the fluctuation of the NH_3 flux from the rumen and the relatively constant flow deriving from metabolism of the host, the load of the liver attributable to the NH_3 excess in the rumen is evident.

These relations between energy and protein metabolism explain the comparable reactions of energy deficit and protein overfeeding: both lead to high NH_3 excess in the rumen, high blood urea contents and hence high milk urea contents, loads of the liver and fertility problems. Moreover an energy deficit always is combined with a lack in BP and hence a lower protein content in milk. Therefore a combination of normal milk protein content together with high urea contents may be a sign for fertility problems caused by protein excess in the ration whereas a low milk protein content with high urea contents may be a sign for fertility problems caused by energy underfeeding.

The negative effects of high protein rations (19%) on fertility are clearly shown by experiments conducted with our Israeli colleagues (Tab. 2, Folman *et al.* 1980) and are also evidenced by experiments from Falaschini (1978) Lotthammer (1980) and Rossow (1980). Jordan and Sawmson (1979) reported an increase in days open (96 till 106 days) and services per conception (1.87 till 2.47) when increasing the protein content of the ration from 16.3% to 19.3% and Treacher *et al.* (1979)

showed in a small group of cows a tendency for decreased fertility when part of the protein was replaced by urea (29 g urea/kg concentrate) which led to higher NH_3 excess in the rumen, a higher load of the liver and hence significantly higher blood urea levels. Senderegger (1976) and Girou and Brochart (1970) also reported a connection between fertility problems and relative protein excess.

The adverse effects of energy underfeeding on fertility can be supported by the results of Kaufmann (1976), who demonstrates an increase in empty time with decreasing milk protein content (Fig. 6) and the recent investigations of Gravert and Pabst (1980) on 208,000 cows, which show a reduced milk protein content in cows culled for fertility problems and a significant increase in days empty with lower protein content.

According to investigations of Spires, Clark, Prior and coworkers (Clark and Davis 1980) NH_3 detoxication may overload liver and cause disturbances in glucose metabolism and hence fertility and yield.

The energy deficit cannot be overcome by fattening in the dry period and using these body reserves in early lactation, because this will lead to fertility problems, too, as could be shown by various workers and techniques: Reid *et al.* (1979) reported an increase in services per conception (1.7-2.4) in fat cows, El-Keraby and Schilling (1976), Lotthammer (1980) and Farries (1979) showed delayed first ovulation, delayed first oestrus, more silent heat, more follicular cysts and more liver disfunctions in the groups supplied with energy and protein according to 16 kg FCM in comparison to 2 kg or 6 kg FCM during the dry period. In addition Haresign (1979) reported that in Frisian cows losing more than 35 kg weight during early lactation the intervals from calving to first oestrus was delayed from 72 days to 104 days.

Overall, the success of first insemination declines from 71% in cows with lactation yields between 2500 - 2999 kg to 28% in cows with yields of more than 6000 kg whereas under excellent conditions the decline amounts from 69 - 45% with no effect on empty time (6573 Lactations, Stemmler and Bach (1979)).

Protected protein

These difficulties in protein metabolism and the relations to milk composition and fertility problems can only be overcome by an optimal energy supply and by using proteins with a lower degradation rate. The calculation in Fig. 7 shows that the optimal degradation rate (no loss of NH_3 in the rumen) declines to about 60 - 65% in high yielding dairy cows with a normal energy supply and to less than 60% in case of energy underfeeding. In contrast to normal FP such proteins allow a better protein supply at the intestine - especially in case of energy underfeeding - without additional NH_3 load and hence an increase in milk protein yield and a better fertility can be expected.

Influsion experiments also suggest an increase in milk yield or milk protein content when additional protein is available for absorption. In these experiments however, protein, nitrogen, and/or energy requirements were often not met (Clark *et al.* 1973, 1977, Derrig *et al.* 1972, 1974, Hale *et al.* 1972, Oldham *et al.* 1980, Ørskov *et al.* 1977, Ranawana and Kellaway 1976, 1977, Rogers *et al.* 1979, Rogers and McLeay 1977, Schwab *et al.* 1976, Spires *et al.* 1973, 1975, Ryrrell *et al.* 1972, Vik-Mo *et al.* 1972, 1974).

Natural protection

The look for proteins with a "naturally" constant low degradation rate available in sufficient quantity and with a high protein quality (amino acid composition) was not very successful. For some protein sources (e.g. fishmeal, bloodmeal, maizegluten, brewers or distillers dried grains, feathermeal, coconutmeal, palm-cernelmeal) lower degradabilities often are reported but this was measured with in vitro methods like solubility or NH_3 -liberation etc. However, these in vitro methods (especially solubility) show no good correlation to degradation measured in fistulated animals (Table 3, Smith *et al.* 1978) and according to vitro experiments from Mahadevan *et al.* (1980) insoluble portions of some proteins can be degraded as fast as the soluble portions. Moreover solubilities vary according to the buffer used, the treatments during production, the origin of the feedstuff etc. (Crawford *et al.* 1978, Klopfenstein *et al.* 1978, Merchen *et al.* 1979, Stern *et al.* 1978, 1979, Waldo and Goering 1979, Wohlt *et al.* 1972, 1973). The investigations of Mehrez *et al.* (1980) clearly show these influences for different sources and processing methods of fishmeal. Furthermore one has to make sure that the protection is limited to the bacterial degradation and the digestibility in the intestine is not impaired.

Therefore the use of proteins with a lower solubility will only randomly and under not controlled conditions increase the protein available in the intestine. It is not surprising that in some experiments positive influence of rations low in soluble proteins (Aitchison *et al.* 1977, Braund 1976, Lane *et al.* 1978, Loosli *et al.* 1960, 1961, Majdoub *et al.* 1977, 1978, Tamminga 1979) are reported whereas others found no influence on production (Burris *et al.* 1973; Davis 1978, Hawkins and Strength 1977, Little *et al.* 1963, Oldham *et al.* 1979). Unfortunately, in some of these experiments solubility was increased by adding urea, which can only be used by rumen bacteria.

Artificial protection of proteins

A better way to reduce protein degradation is a protection of high-protein feed-stuffs with a good protein quality by controlled industrial processes which result in a constantly low degradation rate without impairment of digestibility at the intestine.

If one considers that about 2/3 of the protein supply will derive from roughages (silage, hay, grass) and energy-rich components (grain, tapioka, by-products of the milling industry) one can calculate that the degradation rate has to be decreased to 40% and less in concentrates to achieve a total degradation rate of 60% and less. This can only be reached with a high degree of protection of protein-rich components, otherwise the supplementation of the concentrates with other components will be very limited.

The development and control of such techniques requires laboratory methods for a quick, simple and exact measurement of the protection. This can be done, e.g. by a combination of solubility in phosphate buffer, NH_3 liberation under standardized (constant protein and energy contents) conditions and degradability in bags (Kaufmann and Lipping 1978, Stern *et al.* 1978, Mehrez and Ørskov 1977). However the absolute amount of protection can only be measured exactly in fistulated cows. The restriction to one laboratory method (especially solubility) can induce severe errors (Table 4).

Besides the degree of protection in the forestomachs the digestibility in the intestine has to be measured. Unfortunately laboratory methods (pepsin-HCl-solubility) are not satisfactory. Unpublished results of our laboratory suggest

that the incubation time as well as the HCl-Pepsin-concentration allow a reversability of the formaldehyde-protein-binding, so that in vitro no effect of digestibility could be detected despite great differences measured in vivo. Hence it may be concluded that the differences in rate of passage and HCl-pepsin concentrations in the stomach and abomasum do not allow to measure the influence of such treatments in monogastric animals as tried, e.g. by Rodriguez et al. 1975, Spears et al. 1980 and Thomas et al. 1979. Therefore up to now the influence on digestibility can only be determined in vivo with ruminants.

The apparent digestibility measured in conventional digestibility experiments includes the bacterial transformations in the forestomachs and hindgut and does not allow to determine the absorption in the intestine. Only with the infusion technique influences of treatments on the digestibility in the intestine can be measured. With this method the increase in faecal protein after an additional infusion of protein into the abomasum is measured. According to the carbohydrate content of the protein infused and its influence on bacterial protein synthesis in the hindgut, the digestibility of the treated proteins has to be above the line in Fig. 8, respectively they must be comparable to the untreated proteins (Hagemeister and Kaufmann 1979, Hagemeister et al. 1980, Kaufmann 1979, Kaufmann and Hagemeister 1980, Schwarting and Kaufmann 1978).

All treatments have to be optimized for a maximum of protection in the rumen and a minimum of impairment of digestibility in the intestine.

Heat treatment

Heat treatments have been used by various authors to reduce ammonia formation in vitro in the rumen and to increase nitrogen retention in sheep and calves (Cama and Morton 1950, et al. 1954, 1964, Danke et al. 1966, Glimp et al. 1967, Hudson et al. 1970, Nishimuta et al. 1973, 1974, Sherrod and Tillmann 1962, 1964). Systematic in vitro experiments in our laboratory show the positive influence of short-term autoclaving (15 - 20 Min, 120 - 130°C) on NH_3 liberation with no negative influence on digestibility in the intestine, whereas dry heat was only successful when using longer time and/or higher temperatures (Fig. 9; Kaufmann and Lipping 1978). Under these conditions however adverse influences (Maillard reactions) are likely to occur.

In some experiments with goats and cattle milk yield and/or protein content could be increased (Loosli et al. 1961, Mielke and Schingeothe 1979) when using heat-treated proteins, whereas Ahrar and coworkers (1977, 1979) only found a small positive influence on milk yield in the first stage of lactation but not later on.

Formaldehyde treatment (FA)

The formaldehyde treatment was developed in Australia and is now the most common treatment of protein which has already led to commercially available products. Several review articles have been published in the last years, dealing with the technical side of the treatment, laboratory measurements, feeding experiments (especially sheep) and the limitations of using these products under various conditions (Barry 1976, Beever and Thomson 1977, Brodrick 1975, 1977, Chalupa 1975, Ferguson 1975, Hagemeister 1977). Most of these products show a good protection in the rumen, but digestibility data of the protected proteins measured in the intestine of ruminants are not reported. Only in some experiments (especially with formaldehyde treated roughages) digestibilities of the total protein (including BP) between duodenum and faeces (or ileum) have been published (Beever et al. 1977, Evelplund and Møller 1978, MacRae et al. 1972, Hagemeister

Pfeffer 1973, Kaufmann and Hagemeister 1976, Mühlbach and Kaufmann 1979, Saelzer 1974, Möller and Hvelplund 1978).

Our own experiments demonstrate the positive influence of increasing amounts of formaldehyde on solubility in phosphate buffer and NH_3 liberation in vitro (Figs. 10 and 11). Trials with cows fitted with re-entrant cannulae at the duodenum show that the portion of UDP can be increased from about 30% in normal soybean-protein to about 60-70% in soybean meal treated with 0.2% of FA in D.M. More than 0.2% of FA, however, cannot be used by this technique, because higher amounts reduce digestibility in the intestine markedly (Fig. 12). Treating other protein sources with the same technique and the same amount of FA but with a higher protein content decreases degradation rate in bags (12 h) to less than 10% with no adverse effects on digestibility (unpublished results).

Experiments with the treated soybean meal (Folman et al. 1980, Kaufmann 1979, Kaufmann and Lüpping 1979) show in Israel - compared with the positive control (20% c.p.) - the lower NH_3 content in rumen fluid and the lower blood urea concentration in the group with protected protein (Table 5) and hence a reduced load of the liver.

The better protein supply at the intestine without additional NH_3 losses in the rumen and without additional load of the liver was combined with the expected increase in fertility (Table 2).

The results in Israel and in our research station concerning milk and milk protein yield can be seen in Table 6. In cows as well as in heifers protected protein (pp) allows a higher milk and protein yield. Even with high-producing cows in Israel the group with pp has a tendency for a higher milk yield (+ 1.5 l).

Summarizing the feeding trials reported in literature (Table 7) pp increases milk yield and milk protein yield by about 6%. Only if the amount of FA used was too high so that a negative influence on digestibility is very likely to occur no or negative influences are reported. The same can be expected, if the proportion of treated protein is so high, that the N-supply of the rumen flora may be limited.

Other treatments

Besides the reported heat and formaldehyde treatments, other techniques to reduce degradability have been reported, e.g. treatments with tannins (Delort-Laval and Biroben 1969, Driedger and Hatfield 1972, Hatfield 1973, Rodriguez et al. 1973, 1975, Zelter and Leroy 1966, Zelter et al. 1970), special wood molasses (Hartnell and Satter 1978), other aldehydes and crosslinking agents (Friedman and Broderick 1977, Schmidt et al. 1972, Thomas et al. 1979). Most of these methods are only tested under in vitro conditions, and digestibility data in the intestine are not available but nonetheless first experiments with fattening bulls or lambs show that practical relevant protection may be reached (Driedger and Hatfield 1972, Hatfield 1973, Peter et al. 1970).

Formaldehyde treatment of roughage

The protein of roughage covers under our conditions about 50% and more of the protein requirements. Thus it is obvious to try a protection of these proteins.

Formaldehyde treatments of a clover-grass mixture (0.5% FA in D.M.) however were not successful. Despite a protection - measured by a decrease in rumen ammonia - the amount of digestible protein at the intestine was not changed because the

BP-synthesis and the digestibility in the intestine decreased (Saelzer 1974).

A better way for protecting roughages seems the addition of FA during ensiling, especially of protein-rich direct cut silages. Possibly the cutting and fermentation allows a better reaction between FA and the proteins of the cell content. Moreover besides the protection against degradation in the rumen the desamination during ensiling can be prevented and perhaps FA may also act as a silage additive.

There is ample evidence that FA prevents desamination in the silage if 6 - 9 l formalin per t fresh grass (~0.8 g FA/100 D.M., ~4 - 10 g FA/100 g c.p.) are used together with acids, or more than 7 g FA per 100 g c.p. if formaldehyde is used alone (Barry 1973, 1974, 1975, Barry and Fennessy 1972, Beaver and Thomson 1977, Binnie and Barry 1976, Brown and Valentine 1972, Davidson and Stevenson 1973, Donaldson and Edwards 1977, Ettala *et al.* 1975, Mühlbach 1979, Oshima *et al.* 1979, Tamminga *et al.* 1975, Theune and Honig 1979, Valentine and Brown 1973, Waldo 1977, Waldo *et al.* 1973, Wilkins *et al.* 1974). This relative high amount can be explained, if one considers the high losses (> 50%) during application and the additional losses during ensiling, so that only about 10-20% of the FA used can be detected in the endproduct (Honig and Rohr 1973, Mühlbach 1979, Mühlbach and Kaufmann 1980, Wilson 1972). In accordance with some experiments reported in literature (Amos *et al.* 1979, Arnould *et al.* 1978, Barry and Fennessy 1973, Beaver *et al.* 1977, Beaver and Thomson 1977, Brown and Valentine 1972, Ettala *et al.* 1975, Gill *et al.* 1979, Hvelplund and Möller 1978, 1980, MacRae *et al.* 1972, Möller and Hvelplund 1978, Tamminga 1975, Waldo *et al.* 1973, Wilkins *et al.* 1974) our systematic trials with cows fitted with re-entrant cannulae at the duodenum show on the one hand a reduced FP degradation of FA-treated silage proteins in the rumen, but on the other hand the BP-synthesis and the protein digestibility in the intestine was decreased, so that the total protein available for absorption did not increase (Table 8).

Summarizing, high amounts of FA (> 1.2 g FA/100 g c.p.) prevent a fermentation and degradation during ensilage but these amounts also impair the bacterial activity in the rumen. If FA shall be used successfully as silage additive, the application of FA has to guarantee about 0.35 - 0.8 g FA per 100 g silage protein (as fed). Under practical conditions such an exact rate of application cannot be achieved up to now, especially if one considers the variable protein and dry matter contents in the grass to be ensiled and the great losses during application.

Protected amino acids

In contrast to pp protected amino acids practically cannot reduce the NH_3 excess in the rumen and hence lower the load of the liver deriving from excessive protein. Their action depends upon the optimization of the amino acid supply at the intestine. Therefore, protected amino acids will preferably increase the yields if there are limiting amino acids or a very high requirement for one or two amino acids as, e.g. in sheep, which have a very high requirement for S-amino acids.

According to the high protein quality of the BP and the relatively high portion of BP at the intestine an amino acid deficit is more likely to occur in high-yielding cows. Several workers with different techniques (comparison of amino acid pattern of bacterial and milk protein, amino acid balance, change in amino acid content of the blood after infusion of amino acids or protein into the abomasum, arterio-venous differences, mannery uptake - out-put ratios etc.) show that methionine may be one of the limiting amino acids (Bergen 1979, Bigwood 1964, Champredon *et al.* 1977, 1980, Clark *et al.* 1974, Davis and Bickerstaffe 1978, Derrig *et al.* 1974, Hagemeister and Davis *et al.* 1978, Kaufmann 1978, Hogen 1975,

Kellaway 1974, Mepham 1976, Rohr *et al.* 1979). Unfortunately infusions of methionine into the abomasum or intravenous did not always increase milk yield or milk protein content. But in some trials the protein supply did not cover requirements, so that other amino acids may have become additionally limiting (Erfle and Fisher 1977, Fisher 1969, 1972, Rogers and MacLeay 1977, Rogers *et al.* 1979, Schwab and Satter 1973, Schwab *et al.* 1976, Teichman *et al.* 1969, Clark 1975).

Own results in abomasally fistulated high-yielding dairy cows show, however, that additionally available methionine increases milk protein yield not only in the first third of lactation (Fig. 13) but also in later stages (Table 9). The increase was mainly due to an increase in milk protein content (Kaufmann and Lüpping 1980, Lüpping and Kaufmann 1980).

Comparable to the treatment of proteins the production of protected amino acids must be controlled by a set of laboratory methods whereas the absolute undegraded part and the influence of particle size can only be measured in fistulated cows. The protection can be achieved either by mechanical treatments (coating with a mixture of fatty acids, hydrogenated fat and addition of carbonate, glucose, kaolin etc.) or by chemical modification of the amino acid (formaldehyde treatment, esterlinkages, polymerization) (Amos and Evans 1978, Broderick *et al.* 1970, Buttery *et al.* 1977, Digenis *et al.* 1974, Ferguson 1975, Joassart *et al.* 1980, Neudoerfer *et al.* 1971, Daugaard 1978).

Feeding experiments with protected methionine reported in literature were not encouraging (Broderick *et al.* 1970, Daugaard 1978, Kenna and Schwab 1978, 1979, Williams *et al.* 1970). Own experiments with either chemical modified methionine (HMM-Ca) or a fat-coated material (Loprotin) show, however, significantly positive influences of methionine on milk and milk protein yield in cows whereas in heifers milk protein yield increases to a smaller extent than milk yield because milk protein content declines in these growing animals (Table 10). In these trials in the first third of lactation cows and heifers were fed according to requirements (Kaufmann and Lüpping 1979, 1980, Lüpping and Kaufmann 1980).

The exact way of action on methionine remains to be cleared. The increase in milk protein yield can be explained by its action as limiting amino acid, but not the differences in the response between heifers and cows (decrease in milk protein content of heifers) and infusion (increase in protein content) and feeding trials (increase in milk yield). It seems that methionine has, in addition to its function as limiting amino acid, a direct influence on metabolism (methyl group donor) changes in circulating hormones, (insulin, thyroxine) (Komarek and Jandzinski 1978, 1979, Munro *et al.* 1973, 1975, Neill *et al.* 1979, Oldham *et al.* 1977, Tao *et al.* 1974, Wolf from *et al.* 1979).

SUMMARY AND OUTLOOK

High-yielding dairy cows show increasing difficulties in protein metabolism in the first weeks of lactation, especially if energy requirements cannot be met. Under these conditions the cows have a lack of protein at the intestine which leads to a reduced milk protein content and high ammonia excess in the rumen, which must be detoxicated in the liver and excreted in the urine. Besides the waste of protein the ammonia excess leads to a load of the liver which may be one of the main reasons for fertility problems in these cows.

This situation can only be overcome by using specially treated proteins with a low degradation rate. The best way seems to be the controlled treatment of protein-rich feedstuffs with high protein quality which results in a high degree

of protection (70% and more) and no impairment of digestibility in the intestine. Formaldehyde treatment of roughages is up to now not recommendable under practical conditions.

There is evidence that methionine limits milk production and the supply of protected methionine increases milk protein yield. The exact way of action remains to be cleared. Besides these possibilities to overcome the problems in protein metabolism, in future the development of deaminase inhibitors may be a further way for improving the protein supply of high yielding dairy cows.

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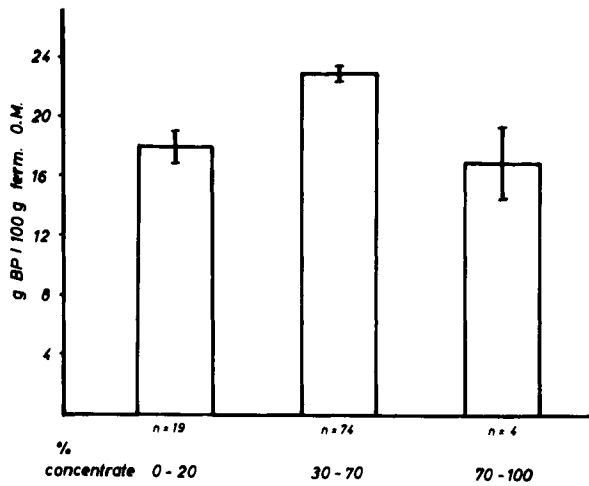
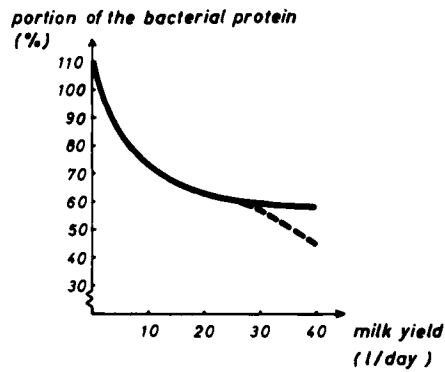


Fig.1

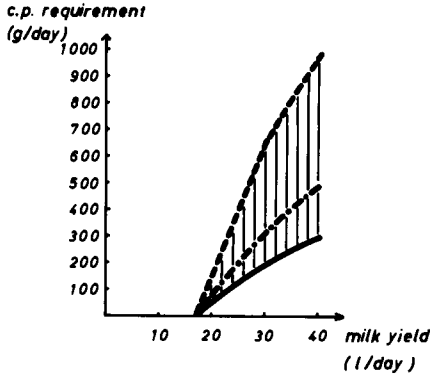
Bacterial protein in relation to the total protein supply at the intestine



energy supply according requirement
energy deficit (max. 600 SE/kg DM,
18 kg DM. intake)

Fig.2

Crude protein requirement of the host in addition to the supply with bacterial protein



c.p. requirement at the intestine
c.p. requirement, degradation rate 70 %
c.p. requirement, degradation rate 40 %

Fig.3

Influence of energy underfeeding on efficiency of utilization of protein

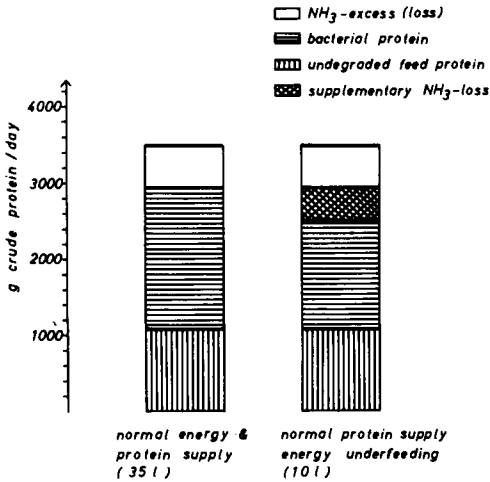


Fig.4

Urea synthesis from $\text{NH}_3\text{-N}$ surplus in the rumen in relation to total urea synthesis

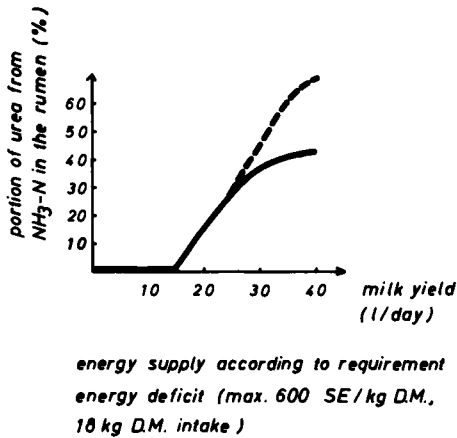


Fig.5

Relation between milk protein content and fertility (3500 cows)

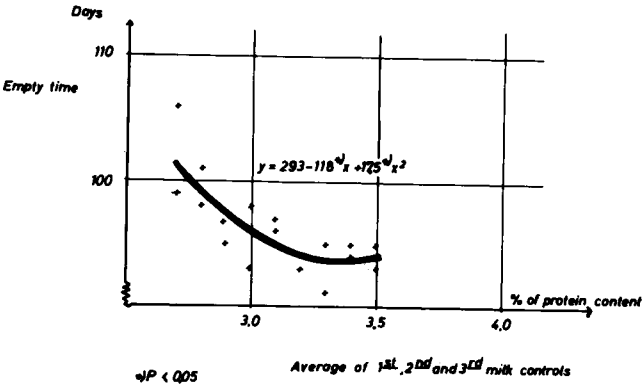
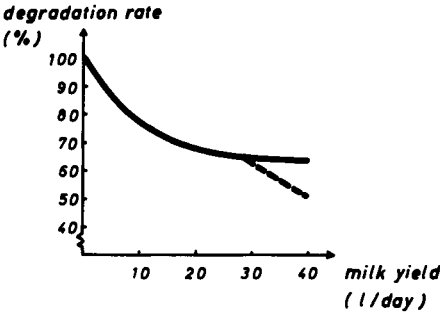


Fig.6

Optimum degradation rate
of feed protein



energy supply according to requirement
energy deficit (max. 600 SE / kg D.M.,
18 kg D.M. intake)

Fig.7

Influence of carbohydrate content of the feedstuff infused
on the protein digestibility in the intestine of sheep

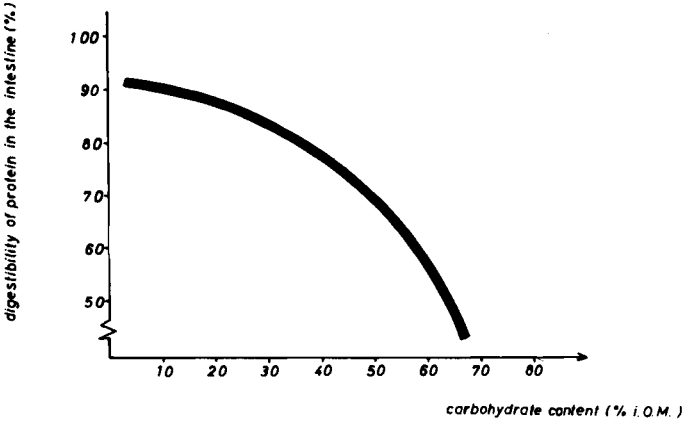


Fig.8

Influence of heat treatment on the
NH₃-liberation of soybean protein

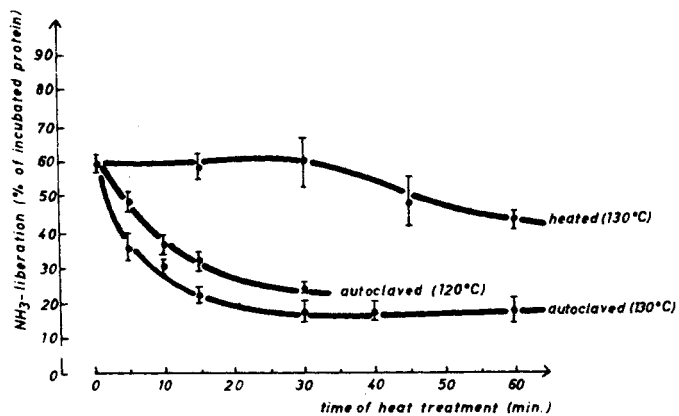


Fig.9

Influence of formaldehyde on the solubility
of soybean protein in phosphate buffer

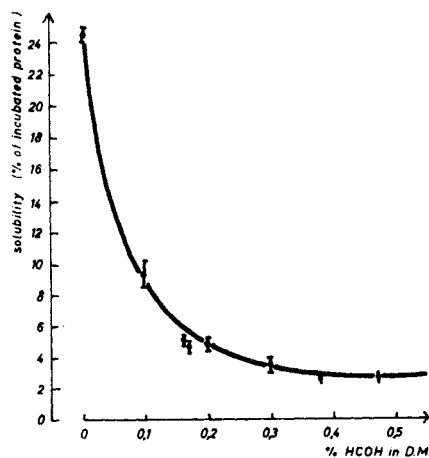


Fig.10

Influence of formaldehyde treatment
on the amount of dietary protein at
the intestine

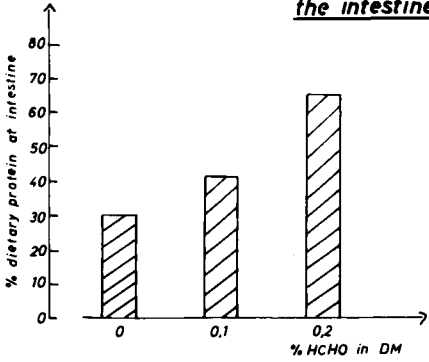


Fig.11

Influence of formaldehyde on the
digestibility of soybean protein

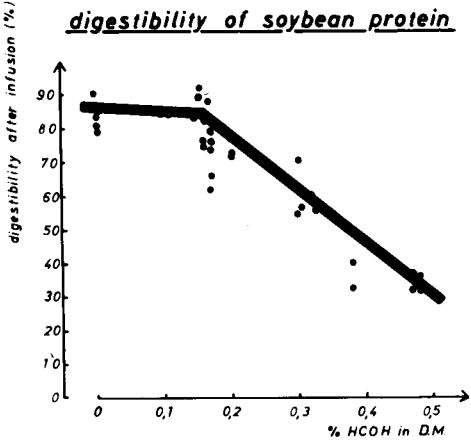


Fig.12

Influence of an abomasal methionine
infusion on milk protein yield

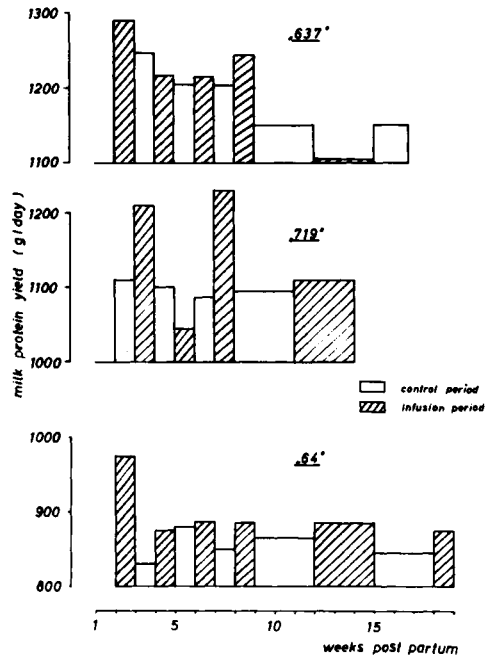


Fig.13

TABLE 1

Feed Protein Degradation in Mixed Rations (measured in cows
with re-entrant fistulae at the duodenum; DAPA, 26 g
endogenous c.p. per kg D.M. intake)

Main protein component	n	degradation rate (%)
ryegrass	6	74
clovergrass	2	76
direct cutsilage/soybean	8	78
hay	3	77
hay/barley/soybean	1	70
hay/oat/soybean	3	72
hay/casein	3	89
hay/soybean	3	70
hay/soybean/fishmeal	3	65
hay/fishmeal	2	84
hay/rapeseed	2	77
hay/groundnut	2	71
hay/horse bean	2	71
hay/coconut	3	61
hay/yeast	3	78

TABLE 2

Influence of Protected Protein and Protein on Fertility

Treatment	16% c.p.	16% c.p. (30% protec. prot.)	20% c.p.
number of cows	19	20	20
rate of conception (%)	56	69	44
inseminations/conception	1.79	1.45	2.25
open days	97.5	83.7	102.1

TABLE 3Protein Solubility and Degradation Rate in Vivo

(steers, T-cannula)

Protein component	solubility (%)		degradation rate (%)
	NaCl	phosphate	
groundnut meal	44	17	68
white fishmeal	21	21	72
heated soybean meal	20	19	67
soybean meal	67	65	85

(Smith et al., 1970)

TABLE 4
Solubility in Phosphate Buffer, NH₃ Liberation, Degradation
in Bags (12 h) and Digestibility in the Intestine of
Different Treated Soybean Meals

Treatment	solubility (%)	NH ₃ liberation (%)	degradation (%)	digestibility (%)
A	39.8	36.3	80	95.1
B	6.5	39.4	92	98.0
C	6.4	8.9	19	79.2
D	5.9	30.4	45	93.6
E	4.9	10.6	10	51.2

TABLE 5
Influence of Protected Protein and Protein on
Rumen Ammonia and Plasma Urea Content

Treatment	n	NH ₃ in rumen mg %	plasma-urea mg %
16% crude protein	19	8.8	7.9
16% crude protein (30% protec. prot.)	20	7.8	7.1
20% crude protein	20	16.8	16.8

TABLE 6

Influence of Protected Protein on Milk and Milk Protein Yield
in the First Third of Lactation (3 experiments)

Type of animal	n		milk yield (kg/day)		protein yield (g/day)	
	contr.	protec. prot.	contr.	protec. prot.	contr.	protec. prot.
cows, Israel	18	18	38.9	40.4	1 179	1 163
cows	9	11	25.4	27.0	780	840
heifers	13	12	18.1	20.1	590	660

TABLE 7
Results of feeding trials with protected protein in dairy cows

Authors	protein source	formaldehyde (g/100 g c.p.)	n	milk yield (kg/day)		protein content (%)	
				contr.	prot.	contr.	prot.
Valentine and Redcliffe, 1975	clover-grass silage	4.7 8.5	21	13.8 13.8	16.3 15.7	3.04 3.04	3.04 2.94
Wilson, 1970	casein (addition)	?	21	14.9	16.6	3.25	3.33
	casein (replacement)			15.8	16.6	3.44	3.33
Broderick and Lane, 1978	casein (replacement)	0.8	8	28.8	29.4	3.06	3.06
	casein (addition)			26.2	27.4	3.23	3.31
Muller et al., 1975	whey-protein	1	4	27.6	29.4	3.14	3.09
Wachira et al., 1973	maize/oat	0.5	6	20.4	20.2	3.24	3.23
Verité and Journet, 1977	soybean/rapeseed	0.6/ 0.9	84	24.6 27.0 17.6	25.5 28.9 18.8	3.23 3.16 3.19	3.32 3.16 3.21
Clark et al., 1974, 1971	soybean	1.8	16	17.8	17.5	3.51	3.43
Satter et al., 1970	soybean	?		19.0	19.0	3.34	3.39
Wachira et al., 1974	soybean	0.5	12 6	21.3 21.0	20.5 21.0	3.33 3.24	3.39 3.23
Kossila and Heikkilä, 1980	soybean	?	2	8.0 7.7	8.5 9.1	4.32 4.25	4.30 4.30
Syrjälä et al., 1978	skim milk powder	0.4	3	19.2	19.7	3.41	3.17
Stobbs et al., 1977	casein (replacement) casein (addition)	0.3	21	12.7 12.3	14.7	3.34 3.30	3.54
Syrjälä et al., 1978	skim milk powder	0.4	16	18.6	17.6	3.56	3.29
Kellaway et al., 1974	casein	1	12	14.8 19.0	15.6 19.0	3.36 2.97	3.37 3.13
Kerma and Schwab, 1978	casein	0.8	5	significantly higher			

TABLE 8

Influence of a Formaldehyde Treatment during Ensiling on Protein
Degradation and Protein Available at the Intestine
(mean of two cows)

Treatment	Control	FA ₁	FA ₂
Application (1/t fresh material)	-	4.6	7.2
FA in silage (% in D.M.)	-	0.07	0.27
(% in c.p.)	-	0.35	1.26
c.p. at the duodenum (% of feed protein)	109	111	114
Degradation rate (%)	74	76	59

¹ 50% of c.p.-intake deriving from silage.

² with 4.2 l formic acid per ton fresh material.

TABLE 9

Influence of a Methionine Infusion into
the Abomasum on Milk Production

Experiment	Milk yield (kg/day)		Protein yield (g/day)		Protein content (%)	
	control	methionine	control	methionine	control	methionine
I	32.7	32.6	1 043	1 072	3.20	3.30
II	16.8	17.4	646	710	3.89	4.13
III	13.6	13.3	513	521	3.76	3.92

I : $\bar{x}$ of daily measurements, 3 cows, 1. - 4. month of lactation,
4 - 6 infusion periods, 22% c.p. in ration.

II : $\bar{x}$ of daily measurements, 3 cows, 7. - 8. month of lactation,
1 infusion period, 13 - 14% c.p. in ration.

III : $\bar{x}$ of daily measurements, 1 cow, 9. month of lactation,
16% c.p. in ration.

TABLE 10

Influence of Protected Methionine on Milk Production
($\bar{x}$ of weekly measurements)

Trial	Number n	Milk yield kg/day	Protein yield g/day	Protein content %
cows				
Trial I control	9	25.4	780	3.13
HMM-Ca	17	27.3	870	3.23
Trial II control	10	26.5	880	3.35
Loprotin	10	28.5	937	3.30
heifers				
Trial I control	13	18.1	590	3.30
HMM-Ca	7	19.9	630	3.20
Trial II control	10	22.4	735	3.30
Loprotin	10	23.8	765	3.25

I : 3. - 14. week of lactation; II : 3. - 16. week of lactation.

The Optimum Protein Supply for Young Fattening Bulls on a High-Energy Level

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1. INTRODUCTION

Ruminal degradation is very extensive for most dietary proteins. Thus, only a minor portion of the protein fed is directly available to the ruminant animal. The degraded nitrogen can only be utilized after incorporation into microbial protein and subsequent digestion in the small intestine. On condition that nitrogen is not limiting, microbial synthesis, again, is essentially governed by the available energy (ATP) derived from carbohydrate fermentation (Armstrong, 1976).

The impact of fermentable energy on microbial yield may, at least partly, explain the protein/energy interactions which have been observed in feeding trials with growing-fattening ruminants. With low-energy rations, an increase in dietary protein often fails to improve animal performance. On the other hand, with high-energy diets, a corresponding rise in protein intake may well produce a higher daily live weight and carcass gain (Preston and Burroughs, 1958; Andres and Ørskov, 1970; Peterson *et al.*, 1973; Griffiths, 1978; Levy *et al.* 1980).

In order to assess the optimum protein intake on high-energy rations, one has to take into account the live weight and growth rate of the respective animal. According to the existing differences in growth potential, protein intake should be higher for late-maturing as compared to early-maturing breeds and higher for bulls as compared to steers and heifers (INRA, 1978).

The object of this paper was to derive the protein requirements of intensively fed bulls from factorial calculations. In order to test the validity of the models used, factorial estimates were compared with the results of two feeding trials.

2. FACTORIAL ANALYSIS OF PROTEIN REQUIREMENTS

The following calculations are made for fast-growing Friesian bulls ranging from 150 kg-550 kg live weight. Example rations consist of 2.3 - 2.8 kg concentrates plus maize silage, with the concentrate being composed of soya bean meal, oats, barley, manioc, wheat bran and minerals. Changes in the protein content have to be achieved by a varying proportion of soy-bean meal in the mixture. The average daily live weight gains (ADG) within different sections of the fattening period are assumed to be as follows: 150 - 250 kg live weight (W) : 1.10 kg, 250 - 350 kg W : 1.25 kg, 350 - 450 kg W : 1.20 kg, 450 - 550 kg W : 1.05 kg. Values on protein deposition (P) are deducted from comparative slaughter experiments (Schulz *et al.*, 1974; Rohr, 1978). Intake of metabolisable energy (IME) is estimated in relation to W and ADG ($\text{IME } \frac{\text{MJ}}{\text{kg}} = 0.152 W + 37.42 \text{ ADG} - 26.7$ [Rohr, 1980]).

2.1 Derivation of digestible crude protein (DCP) requirements

Digestible crude protein is controversial as a measure for the protein requirements of ruminants, because it neglects the complex pre-omasal N-conversions. However, as DCP is still in general use in most countries, derivation of corresponding requirements cannot be dispensed with here.

Endogenous excretions via faeces and urine amount to between 300 mg and 450 mg N/kg $W^{0.75}$ (van Es, 1972; Dielanowski, 1972; Ørskov *et al.*, 1980). Accordingly, the maintenance requirements of DCP can be estimated at $3 \text{ g/kg}^{0.75}$ (Schulz *et al.*, 1974; Jentsch *et al.*, 1975; INRA, 1978). If an amino acid content of 80% of the DCP and utilization of absorbed amino acids for body protein accretion of 75% is assumed, this leads to utilization of the DCP for deposition of 60%. Such an efficiency of utilization of DCP has been adopted as well by Jentsch *et al.* (1975) as by Poppe and Gabel (1977). Total DCP-requirements may hence be calculated as follows:

$$\text{DCP (g/d)} = 3 \times \text{kg } W^{0.75} + \frac{\text{Protein deposited (g/d)}}{0.6}$$

As far as our example is concerned, this equation leads to the DCP-requirements listed in Table 1 (rounded off to the nearest 5 g).

The necessary amount of digestible crude protein increases from 450 g at 200 kg W to a maximum of 595 g at 400 kg W. With the given concentrate to forage ratio, the calculation DCP-values imply a proportion of between 29 and 15% of soya-bean meal in the concentrate mixture. Corresponding to this formulation of the diet, the crude protein (CP) content in dry matter (DM) decreases from 15.2% at the beginning to 11.1% at the end of the fattening period.

2.2 Derivation of the requirements for protein digested in the small intestine

On account of the above-mentioned fact that digestible crude protein neglects the complex catabolic and anabolic processes within the rumen, the question arises whether the protein absorbed in the small intestine (PDI) has to be selected in the future as a measure for requirements. PDI is obtained as the sum of the digestible microbial protein and of the digestible portion of the feed protein not degraded in the rumen. In the following analysis, the calculation of PDI is carried out in accordance with the INRA (1978) procedure. Starting from the experimental data available, microbial synthesis in the rumen of 135 g crude protein/kg digestible organic matter is assumed.

The digestibility of amino acid N (80% of microbial CP) is estimated to be 70%; the nucleic acid N is left out of account. The content of undegraded protein and its true digestibility is derived for the different feedstuffs from studies of Demarquilly *et al.* (cited after INRA, 1978).

INRA (1978) determined a 63% utilization of the PDI for body protein deposition and a maintenance requirement of $3.25 \text{ g PDI/kg}^{0.75}$. If the respective total requirements of PDI are calculated from these data, only small deviations are found as compared to the DCP-requirements (Table 2).

Nevertheless, the due changes in concentrate composition of our example rations are remarkable: the percentage of soya-bean meal decreases from 41% at the beginning to 0% at the end of the fattening period. According to the French model, there is already a lack in rumen-degradable nitrogen (RDN) at 300 kg W. This deficit in RDN becomes very pronounced at 500 kg W; it is compensated for

in our example by the addition of urea. The decrease in the crude protein content is rather steep: from 17.9% CP in DM at 200 kg W to 11.8% at 500 kg W.

3. THE OPTIMUM PROTEIN SUPPLY DERIVED FROM FEEDING EXPERIMENTS

The effect of a graded protein supply on animal performance was studied in two experiments, using a total of 108 Friesian bulls (7 groups of 15 resp. 12 animals each). Animals were offered fixed amounts of concentrates (as indicated in Table 1) and maize silage (95% ad lib.). Concentrate ingredients were the same as mentioned in Chapter 2 (soy-bean meal, oats, barley, manioc, wheat bran, minerals). The protein content was manipulated by changing the proportion of soya-bean meal in the concentrate.

In spite of the fact that maize silage was fed nearly ad lib., figures for dry matter intake and concentrate to forage ratio were almost identical with those listed in Table 1. Data on estimated IME (Gesellschaft für Ernährungsphysiologie der Haustiere, 1979) and crude protein content (% in DM) are given in Tables 3 and 4.

IME was similar for all groups in both experiments and amounted to 69.2 MJ/d on an average (11.4 MJ ME/kg DM). The crude protein content in dry matter varied between 9.5% and 14.2% in Experiment I and between 11.9% and 15.1% in Experiment II (mean of the whole feeding period).

The influence of protein concentration on daily live weight gains at different sections of the fattening period is shown in Figure 1. An energy intake was nearly the same for all groups, the results of both experiments are treated as one set of data in this graph. Letters A-G represent the ADG of the seven experimental groups.

The intersection of dotted lines indicates the optimum protein level, i.e. the point at which live weight gain ceases to increase with increasing protein intake. The respective optima for different live weight sections were as follows:

<u>Live weight</u> <u>(kg)</u>	<u>Optimum protein level</u> <u>(% CP in DM)</u>
200	14.5
300	13.0
400	12.5
500	11.0

Measurements of organic matter digestibility on rations A, B and C (4 wether sheep per treatment) indicate that the decline in ADG at sub-optimal protein levels was mainly due to a protein deficit per se and not to a decrease in energy digestibility (Table 5).

Dressing percentage and proportion of lean, fat, and bones in bulls' carcasses - as measured by section of the three rib cut - were not significantly influenced by protein supply.

4. COMPARISON OF FACTORIAL ESTIMATES WITH RESULTS OF THE FEEDING TRIALS

In spite of the questionable physiological meaning of digestible crude protein, factorial calculation of DCP requirements led to a protein content of the diet which was similar to the optimum protein level derived from feeding experiments.

On the other hand, protein concentrations as resulting from factorial PDI calculation did not coincide with the results of the feeding trials. The discrepancy was most pronounced at the beginning of the fattening period: a protein content of 17.9% according to the factorial analysis stands opposite to a value of 14.5% in the feeding trials. Apparently, the general applicability of the factorial PDI approach presupposes more basic research on the following topics: (a) microbial synthesis and protein degradation in relation to diet composition, (b) incorporation of recycled N into microbial protein, (c) availability of amino acids derived from microbial protein and undegraded feed protein.

5. SUMMARY

In this paper the requirements of intensively fed Friesian bulls for digestible crude protein and for protein digested in the small intestine were derived from factorial calculations. Example rations consisted of 2.0 - 2.5 concentrate DM plus maize silage. In order to test the applicability of the models used, factorial estimates were compared with the results of two feeding trials. In these trials with a total of 108 bulls (7 groups of 15 resp. 12 animals each), concentrate to maize ratio was the same as in the theoretical example. Intake of metabolisable energy was very close to the predicted values ($\text{IME} \frac{\text{MJ}}{\text{d}} = 0.152 \text{ kg W} + 37.42 \text{ kg ADG} - 26.7$). Protein content in ration dry matter varied between 9.5 and 15.1% (mean of the whole feeding period).

In spite of the questionable physiological meaning of the digestible crude protein, factorial calculation of DCP requirements led to a protein content of the diet which was similar to the optimum protein level derived from feeding experiments. On the other hand, protein concentrations, as resulting from factorial calculations of protein absorbed from the small intestine, did not coincide with the results of the feeding trials. This discrepancy indicates that more basic research on ruminant N metabolism is needed.

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Table 1
Factorial Estimate of DCP Requirements and Corresponding Formulation of the Diet

Live weight (kg)	Live weight gain (kg/d)	Protein deposition */ (g/d)	DCP- requirements (g/d)	IME (MJ/d)	DM intake (kg/d)		Soya bean meal (% of concentrates)	Crude Protein (% in DM)
					from concentrates	from maize silage		
200	1.10	175	450	44.9	2.05	1.02	28	15.2
300	1.25	210	565	65.7	2.20	3.58	29	13.6
400	1.20	195	595	79.0	2.35	4.66	25	12.4
500	1.05	150	570	88.6	2.50	5.41	15	11.1

*/ including surface losses of 0.125 g protein/kg W^{0.75}

Table 2
Factorial Estimate of PDI Requirements and Corresponding Formulation of the Diet

Live weight (kg)	Live weight gain (kg/d)	Protein deposition (g/d)	PDI- requirements (g/d)	IME (MJ/d)	DMI intake (kg/d)		Soya bean meal (% of concentrates)	Crude Protein (% in DM)
					from concentrates	from maize silage		
200	1.10	175	450	44.9	2.05	1.30	41	17.9
300	1.25	210	570	65.7	2.21 ^{*/}	3.58	35	14.8
400	1.20	195	600	79.0	2.39 ^{**/}	4.68	18	13.3
500	1.05	150	580	88.6	2.59 ^{***/}	5.43	-	11.8

^{*/} including 10 g urea)
^{**/} including 44 g urea)
^{***/} including 39 g urea)
to overcome a deficit in rumen degradable N

Table 3
Intake of Metabolisable Energy (IME) and Crude Protein (CP)
Content of the Diet in Experiment I

Live weight (kg)	Group A (n = 15)		Group B (n = 15)		Group C (n = 15)	
	IME (MJ/d)	CP (% in DM)	IME (MJ/d)	CP (% in DM)	IME (MJ/d)	CP (% in DM)
200 (150 - 250)	45.3	10.73	46.4	13.33	45.6	16.53
300 (250 - 350)	65.7	9.61	64.8	12.07	64.7	14.72
400 (350 - 450)	80.9	3.98	80.6	11.01	79.3	13.61
500 (450 - 550)	87.7	9.11	87.9	10.92	87.1	13.34
150 - 550	69.7	5.46	70.1	11.59	69.6	14.23

Table 4
Intake of Metabolisable Energy and Crude Protein Content of the Diet in Experiment II

Live Weight (kg)	Group D (n = 12)		Group E (n = 12)		Group F (n = 12)		Group G (n = 12)	
	IME (MJ/d)	CP (% in DM)	IME (MJ/d)	CP (% in DM)	IME (MJ/d)	CP (% in DM)	IME (MJ/d)	CP (% in DM)
200 (150 - 250)	44.8	12.99	45.0	14.76	43.4	16.28	45.2	17.53
300 (250 - 350)	64.6	11.78	63.2	12.95	64.4	14.16	62.6	15.41
400 (350 - 450)	78.9	11.62	77.5	12.69	79.3	13.50	79.6	14.39
500 (450 - 550)	87.1	11.50	85.5	12.58	88.6	13.32	87.5	14.28
150 - 550	68.8	11.87	68.0	13.05	68.8	14.04	69.1	15.10

Table 5Digestibility of Organic Matter of Rations Differing in Crude Protein Content

Diet	Concentrate: maize silage (DM basis)	Crude protein (% in DM)	Digestibility of organic matter (%)
A	45 : 55	9.0	78.0
B	45 : 55	11.7	79.7
C	45 : 55	14.7	79.8

Table 6
Dressing Percentage and Composition of Best Ribs of Bulls in Experiment I and II

	Experiment I				Experiment II		
	A (9.5% CP)	B (11.6% CP)	C (14.2% CP)	D (11.9% CP)	E (13.1% CP)	F (14.0% CP)	G (15.1% CP)
Dressing percentage	58.2	58.7	58.3	57.8	57.8	57.2	57.9
Composition of best ribs (%)	64.						
Muscular tissue	64.9	64.1	62.9	64.0	66.2	63.7	63.2
Adipose tissue	18.0	20.7	21.5	19.0	17.6	19.7	20.5
Bones	17.1	15.3	15.6	17.0	16.2	16.6	16.3

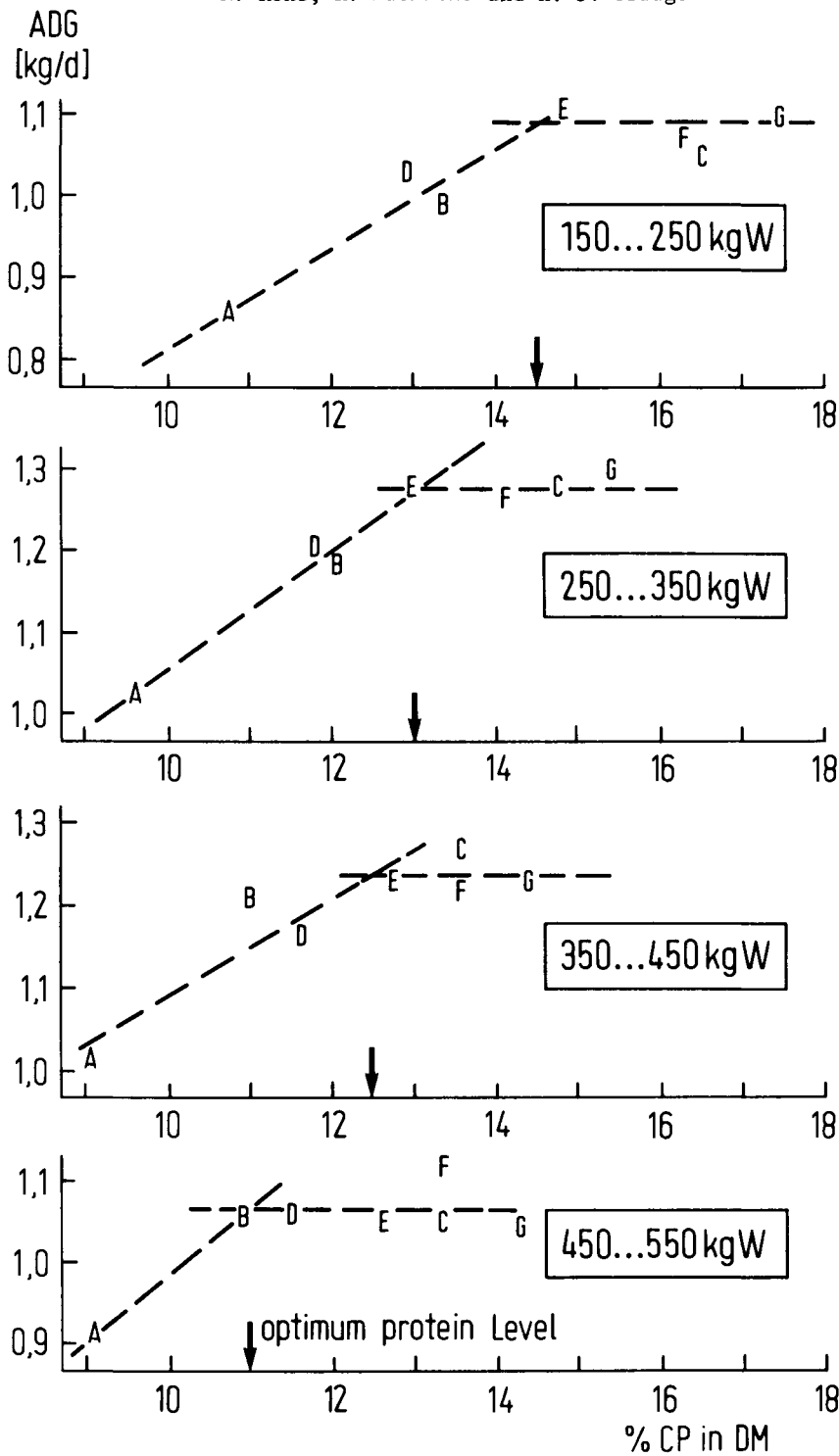


Fig.1: The influence of protein concentration
on daily live weight gains

Present Experimental Results on Protein: Energy Relationships in the Feeding of Dairy and Beef Cattle in Denmark

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1. INTRODUCTION

The relationship between protein and energy in rations for ruminants is of great importance for obtaining a maximal utilization of the nutrient supply for both milk and beef production. The requirements forwarded and used in practical feeding until recently were obtained in static-designed feeding experiments with relatively low producing cows yielding on the average 15-20 kg FCM daily. During the last decades milk production has increased to about twice the mentioned production level. For this high level of milk production which mainly is obtained early in lactation, reliable investigations about the response of these cows to varying inputs of protein and energy have been conducted during the last years. At this stage of lactation, the mobilization of body reserves of both energy and protein interrelates with the energy and protein supply.

Until new systems of protein evaluations are introduced, the present protein requirements are expressed as digestible crude protein in total amounts per day, per kg of milk, or per level of energy unit.

New evaluation systems concerning the quality of protein for ruminants will be based on the degradation of different plant protein sources by ruminal micro-organisms which imply the importance of the amount of feed protein passing the rumen undegraded to the small intestine, where amino acids can be absorbed and used in the intermediary metabolism for protein synthesis or act as glucogenic agents especially in early lactation. For the purpose of supplying the animal with protein at the duodenum the ruminal bypass of protein can be obtained by protecting protein sources against microbial degradation by treatment with formaldehyde or other chemical agents.

As the purpose of the symposium is to discuss the practical use of protein in relation to energy supply, this report is mainly concerning the current knowledge and future ideas of practical application of the protein/energy relationships for the production of milk and meat.

2. PROTEIN: ENERGY RELATIONSHIPS IN THE FEEDING OF DAIRY COWS

An understanding of the practical relationships between the protein requirement and the energy supply for ruminants has been put forward in a graphic model by Balch (1967). This is diagrammatically shown in Fig. 1. The figure shows the response in nitrogen balance between increasing amounts of nitrogen in the feed and different levels of energy. The response expressed in nitrogen balance could be exchanged either by the response in milk production or daily live weight gain. It is illustrated that the maximal response to a certain input of nitrogen (protein) can only be obtained if the appropriate energy level is applied.

When energy is limiting the response per unit of protein increment is diminishing. If energy is not limiting the increasing response per unit of protein can be explained by the present knowledge of interaction in rumen fermentation between microbial protein synthesis and the fermented amount of energy (ATP) available for microbial protein production. If the level of fermentable energy intake can be increased and combined with the appropriate amount of degradable protein, more microbial protein will be synthesized in the rumen and passed to the small intestine for absorption of the amino acids. The described relationship between protein and energy was recently confirmed in a central composite-designed experiment in early lactation including 172 lactating dairy cows in which the protein and energy intakes were varied systematically (Krohn and Andersen, 1978). The obtained milk production curves are shown in Fig. 2 and confirm the basic response relationships between protein and energy input at different intake levels of 12, 14 and 16 Scandinavian feed units for milk production (PFU). The amounts of protein are stated in terms of digestible crude protein which is the expression used at the present stage in the development of protein evaluation.

Economic considerations between the optimal protein input/energy unit and the output in milk were constructed by Andersen et al. (1973). These calculations were based on several milk production experiments and are generally valuable for all responses in milk output levels of 15-20 kg daily at increasing inputs of protein/unit of energy (PFU). The response curves which are grafically shown in Fig. 3 imply an increasing response in milk output by adding up to 165 g dig. crude protein per PFU. From this response curve the profit margin can be calculated by differentiation. The figure illustrates a decreasing marginal output of milk at increasing amounts of dig. crude protein per PFU. The marginal output is zero where the maximal amount of 165 g DCP per PFU was found. If the price relationships between the sources of energy and protein are known the economically optimal amounts of protein for milk production can be calculated. This is illustrated in the diagram at the bottom of Fig. 3 showing the marginal income of milk (MI) and marginal cost of supplemental protein (MC) in relation to increasing amounts of protein per unit of energy. Taking the economic price relations between the extra supplementation of protein and the milk into consideration, the optimal amount of protein is obtained, where the marginal income is equal to the marginal cost (MI = MC). If for example the price per kg of milk is 90 øre, and the price per kg of supplemental protein is 400 øre, Fig. 3 illustrates the economic optimal amount of protein to about 120 g/PFU. If the price for milk is increased to 110 øre per kg of milk then the optimal amount of protein will increase to about 130 g/PFU at the same cost of supplemental protein. The biological maximal amount of protein of 165 g/PFU will only be economical if the price of supplementary protein or if the cost of additional protein is equal to the price of the energy source used in the feed ration. These price relationships show that the biological maximal amount of protein does not commonly coincide with the economically optimal amount of protein. For further detailed information about the calculations of the economic price relationships between milk output and protein input per unit of energy see Møller and Neimann-Sørensen (1977). In this paper also the experimental investigations on the biological and economic responses of substituting plant protein with urea to lactating dairy cows are described in great detail (Møller and Neimann-Sørensen, 1977).

The economically optimal daily amounts of urea to lactating dairy cows can be calculated from the following equations:

High milk yield:

$$\text{g urea/day} = 29 + 27 \times \frac{\text{price (suppl. plant protein - urea "protein")}}{\text{milk price}}$$

Low milk yield:

$$\text{g urea/day} = 76 + 21 \frac{\text{price (suppl. plant protein - urea "protein")}}{\text{milk price}}$$

The functions show that maximum milk yield is obtained for low yielding cows by substituting an equivalent amount of plant protein by 76 g of urea whereas only 29 g of urea can be supplied to higher milk yields.

Further biometrical evaluations of the systemically designed experiments by Krohn and Andersen (1978) describing the protein-energy relationships in early lactation were used to calculate the biological and economical amounts of protein for milk production during early lactation. In these experiments the interrelationships between energy intake, body energy mobilization and milk production were considered. The maximum amounts of protein/unit of energy at different levels of energy intake are shown in Table 1, and the related production functions are shown in Fig. 4.

Table 1 and Fig. 4 demonstrate the interactions between energy and protein at different levels of DCP per unit of energy. At increasing energy intake early in lactation the maximum amount of protein/unit of energy required is decreasing from 205 g DCP/PFU at an energy intake of 8 PFU to 167 g DCP/PFU at an intake of 12 PFU. At these input levels the daily loss in body weight was decreasing from -540 g/day to -60 g/day. These data demonstrate a reduced mobilization of body reserves for milk production during early lactation at increasing levels of energy intake.

The economically optimal amounts of DCP/PFU were calculated by taking the interactions of feed and protein intake into consideration. The following generally valuable formula including the price relations between protein and milk was constructed:

$$\text{g DCP/PFU} = 165 - 10 \times (\text{consumed FU} - \text{required FU}) + \frac{\text{Price suppl. protein}}{\text{milk price}}$$

The increase in milk production with an increasing intake of energy containing the same amount of protein/unit of energy can be explained by an increase in the total amount of microbial protein synthesized in the rumen. In this connection a greater rate of passage on the higher feeding level of undegraded feed protein out of the rumen supplying a greater amount of protein to the small intestine for absorption and utilization for intermediary synthesis purpose must be assumed.

Taking these relationships into consideration requirements of DCP/PFU can be calculated at varying intakes of energy and production levels of high producing cows (Krohn and Andersen 1978).

3. THE INFLUENCE OF DIFFERENT ENERGY SOURCES ON THE UTILIZATION OF UREA-N

Generally the source of energy has a large influence on bacterial growth in the rumen as shown by in vitro and in vivo measurements (Walker and Nader 1970, Kaufmann and Hagemeister 1975, Møller and Hvelplund 1978 a, b, Hvelplund and Møller 1978). Most of the readily available carbohydrates benefit NPN utilization, but some differences exist (Møller 1973). Some mono- and disaccharides are fermented too rapidly to favour maximum protein synthesis from ammonia by the microorganisms, whereas starch products have been more adequate energy sources (Belasco 1956).

Important is the fermentation of energy in the rumen compared to the NH_3 liberation to obtain maximum utilization by microorganisms (McMeniman et al. 1976, Johnson 1976, Møller and Ahmed 1977).

Experiments by Møller (1973) on the influence of different carbohydrate sources on the utilization of urea nitrogen by lactating dairy cows showed significant interactions between different sources of starch, soya bean meal and urea. The following carbohydrate sources were investigated: Maize, oats - tapioca (1 : 1), barley, tapioca, oats and molassed beet pulp. The relationship between the nitrogen utilization and the intake of digestible energy of the different starch sources is shown in Fig. 5 and Table 2. The nitrogen utilization is related to the digestible energy because the synthesis of microbial protein in the rumen depends on the amount of energy fermented, or the intake of digestible energy as also was found by Ørskov (1976). The results showed the highest utilization of urea-N, when starch from barley was fed as the starch source which is in agreement with a higher rate of energy fermentation in the rumen, as the concentration of $\text{NH}_3\text{-N}$ /100 ml rumen fluid was raised to 13.8 mg $\text{NH}_3\text{-N}$ as compared to 4.7 mg $\text{NH}_3\text{-N}$ on the same ration without nitrogen addition. With soya bean meal the nitrogen utilization was below that of urea, which may depend on an overprotection of the soya bean meal used or a too low amount to assure optimal microbial protein synthesis or energy fermentation in the rumen. On the rations containing tapioca or molassed beet pulp without protein addition the $\text{NH}_3\text{-N}$ -concentration again was too low to assure an optimal energy fermentation and microbial protein synthesis in the rumen, which could be increased by the addition of urea. In these cases again some of the soya bean meal must have passed undegraded to the duodenum resulting in a higher nitrogen utilization as compared to urea nitrogen.

On the ration with oats as the source of starch the $\text{NH}_3\text{-N}$ -concentration of 7.6 mg $\text{NH}_3\text{-N}$ /100 ml rumen fluid must have been adequate to assure an optimal fermentation, which could not be increased by addition of urea increasing the $\text{NH}_3\text{-N}$ -concentration to 14 mg $\text{NH}_3\text{-N}$ /100 ml rumen fluid. Soya bean meal again must have passed undegraded to the intestine, as $\text{NH}_3\text{-N}$ -concentrations on the average could not be raised above 9.9 mg $\text{NH}_3\text{-N}$ /100 ml rumen fluid. On the ration containing maize, the $\text{NH}_3\text{-N}$ -concentration on the protein-deficient ration was adequate to assure an optimal fermentation and bacterial protein synthesis. Addition of urea or soya bean meal did not increase the nitrogen utilization or milk production significantly. Furthermore the curves for utilization of urea-N with barley show a more horizontal relationship indicating a constant synthesis of microbial protein/unit of energy fermented, whereas the other curves show an increase in the nitrogen utilization with an increase in intake of digestible energy. Relating the utilization of urea-N on the different energy sources to soya = 100, the following order was obtained: (1) barley, (2) maize, (3) molassed beet pulp, (4) tapioca, (5) oats, (6) oats-tapioca. The urea utilization on the oats and oats-tapioca rations was significantly decreased. The influence of different energy and protein sources on the degradation of protein in the forestomachs and the synthesis of microbial protein determined by the method developed by Hvelplund et al. (1976) is shown in Table 3.

The influence of the different energy sources on the synthesis of microbial protein is obvious, especially for the rations containing barley + urea and beets + urea. On these rations the degradation of feed protein was as high as 92 and 97% respectively, and the equilibrium point of NH_3 accumulation in the rumen was determined at 13 and 10% respectively. These results indicate an important influence on the utilization of NPN in the rations for ruminants by the source of energy and protein as well as the treatment and percentage of protein in the ration. These factors must be considered in evaluating the response of milk production to a certain input of urea.

4. PROTEIN:ENERGY RELATIONSHIPS IN THE FEEDING OF BEEF CATTLE

Regarding the protein needs for beef production only the growth of young bulls shall be considered.

In discussing the response of beef cattle to varying inputs of protein to energy, reference shall be made to the predicted model of responses to different protein:energy relationships by Balch (1967) as shown in Fig. 1. A support of the protein utilization by beef cattle according to the predicted model can be calculated from experimental data by Thorbek (1980) as shown in Fig. 6. Nitrogen balance and energy metabolism studies were investigated on bull calves from 100 to 275 kg live weight on high energy level (HE) corresponding to 11 Mcal ME daily and on low energy level of about 6 Mcal ME daily (LE). The average daily live weight gain varied between 1100-1500 g on the HE level and no increase in daily live weight was obtained on the LE level fed close to maintenance. Within feeding level (HE or LE) Fig. 6 illustrates no increase in nitrogen retention with increasing amounts of nitrogen/unit of Mcal ME which implies a maximum level of nitrogen per unit of energy in the considered range. Taking the necessary precautions of the reliability of nitrogen balance data into consideration, Fig. 6 clearly illustrates a significant increase in nitrogen retention from an average of 14 g N on LE to 43 g N by increasing the level of energy from 6 to 11 Mcal ME daily. This clearly illustrates the effect of the level of energy on the nitrogen retention by growing ruminants as proposed by Balch (1967). Probably the results can be explained by an increased microbial protein synthesis to supply the animal's need of protein with increasing intake of energy which is in accordance with our present knowledge about the ruminal microbial protein syntheses and energy supply.

The highest intensity in daily live weight gain of young growing bulls is obtained during the first 5.5 months of age as shown in Fig. 7 by Andersen (1975) corresponding to a live weight between 40-230 kg. The interpretation of a decrease in daily LWG beyond 220 kg LW is probably the reduction in protein retention and an increase in fat deposition at increasing live weight shown by Thorbek (1980) and Daenicke and Oslage (1980).

Economic relationships between protein:energy including the price of meat and supplemental protein in raising young bulls for meat production are calculated by Andersen et al. (1973) and shown in Fig. 8. The figure illustrates an increase in daily live weight gain expressed per unit of Scandinavian Feed Units (SFU) with increasing the amount of protein/SFU unit up to 125 g DCP. Beyond this amount of protein no increase in LWG was observed. The figure showing the marginal output (MO) by increasing the protein level illustrates a slightly negative marginal output at levels above 125 g DCP/SFU. The economic optimal amount of protein again can be calculated if the price of meat and supplemental protein is known. The figure at the bottom of Fig. 8 illustrates an optimal amount of 115 g DCP/SFU if both the price of meat and supplemental protein are 6.00 kr/kg. If the meat price is increased, higher amounts of protein will be economically optimal. These relationships are expressed in the following equation which is generally valid in the considered live weight range:

$$\text{Economical optimal amount of protein/SFU} = 125 \times 20 \times \frac{\text{Price suppl. protein}}{\text{Meat price (LWG)}}$$

The present protein requirements for beef production by Sørensen and Kousgaard (1976) are shown in Table 4. With increasing live weight of the animal the protein requirements are shown to decrease per unit of energy (SFU) input. The total daily amounts of g DCP are increasing up to 550 g at 350 kg LW and constant at increasing live weight. Calculated amounts of microbial protein synthesis in the

rumen, assuming 100 g of microbial protein/SFU, show a sufficient daily supply of digestible microbial protein of 560 g (dig. coeff. 80%) at the animals intake of 7.0 SFU corresponding to live weights from 350 kg and upwards. A comparison of standards between different countries at different live weights of the animal is shown in Fig. 9

5. UREA AS A SUBSTITUTE FOR PROTEIN IN THE FEEDING OF BEEF CATTLE

Substituting about 30% of the protein supply by urea nitrogen in rations for beef cattle did not reduce the performance in live weight gain (Piatkowski 1966, Brüggemann et al. 1962, Studt 1958 and King et al. 1957).

The critical range in live weight by introducing urea into rations for young ruminants to secure maximum growth rates is from the beginning of rumination until about 200-250 kg live weight. As shown in Table 4 the ruminal microbial protein synthesis cannot supply the growing animals' need of protein until a live weight of about 300-350 kg has been reached. Below this live weight natural protein sources have to be added to the ration to secure the protein supply of the animal.

Investigations about the ability of young ruminants to utilize urea nitrogen as a part of the protein supply have been carried out by Madsen and Møller et al. (1977). In two nitrogen balance experiments with bull calves from 170-240 kg live weight, the utilization of urea by using starch products (barley, tapioca or cellulose + soluble carbohydrates, molassed beet pulp) as the energy source was investigated. The results are shown in Table 5. To assure a total consumption of the offered amounts of feed, the energy supply was reduced as compared to standards. For measuring the response in nitrogen utilization the crude protein content of the rations was reduced to about 13% of the dry matter. The ration containing molassed beet pulp only (experiment 2) did not contain more than 8.8% protein in the DM as the basic level. Urea substituted from 26.3 - 28.7% nitrogen in experiment 1 and from 39.3 - 42.0% nitrogen in experiment 2. In spite of the low protein level in the rations the results of experiment 1 with starch as the energy source showed satisfactory growth rates of the urea groups as compared to soya bean meal as the protein source. The nitrogen balance data of the urea groups were not significantly different from the results of the soya group. In experiment 2 with molassed beet pulp as the main energy source the daily gain of the group without any urea addition was below the expected values in relation to the energy intake. The results of the urea-N supplied as Triple nuts or DUB showed significant increases of the measured N-balance data as compared to no urea supplementation. The daily live weight gain of these groups showed a satisfactory increase as compared to no urea supplementation, taking the relatively low level of energy intake into consideration. These results indicate a positive effect of urea as a nitrogen source if a readily fermentable energy source is included in the rations to young growing bull calves for the purpose of meat production.

6. FUTURE CONSIDERATIONS TO IMPROVE THE EVALUATION OF PROTEIN FOR RUMINANTS

Recent experimental results of nitrogen metabolism in ruminants have clearly shown the use of digestible crude protein as a factor for determining the quality of protein for ruminants as being insufficient. Therefore new systems including factors important for protein evaluation and utilization for ruminants have been put forward by Roy et al. (1977) and INRA (1978). These two systems rely on the same basic principles, but great differences are existing between the systems in the practical application as described by Madsen (1979). Investigations on

intermediary protein metabolism seem to agree on the following factors as being important for determining the protein requirement in ruminants:

1. Protein content in milk
2. Metabolic faecal nitrogen
3. Endogenous urinary nitrogen
4. Gluconeogenesis
5. Protein mobilization/deposition
6. Amount of urea-N recycled to the rumen

For practical application of new systems of protein evaluation for ruminants the following factors are considered as important for determining the utilization of protein by ruminants:

1. Degradation of protein in the rumen
2. Synthesis of microbial protein
3. Digestibility of microbial protein in duodenum
4. Digestibility of feed protein in duodenum
5. Fermentation of energy in the rumen
6. The carbohydrate composition of the ration

Especially the degree of microbial protein degradation within the rumen is of importance in determining the amounts of undegradable or degradable protein necessary for optimal protein utilization. Measurements of the protein utilization by using new techniques as duodenal re-entrant cannulated animals as well as digesta and microbial markers have yielded results on different degradabilities of different protein sources as well as microbial protein synthesis of different ration composition. The expensive and time-consuming in vivo investigations by using animals have made it necessary to look for more simple techniques in determining protein degradation in the rumen as e.g. the nylon bag technique introduced by Mehrez and Ørskov (1976). Results of the protein degradation of soya bean meal (SBM), cotton seed meal (CSM), and fish meal (FM) at different hours of incubation obtained by the use of the nylon bag technique are shown in Fig. 10. These results must be converted to rumen fermentation conditions by taking the outflow rate of the protein out of the rumen into consideration as shown in Fig. 11. This figure shows the effective degradation of SBM, CSM, and FM by using the degradation rate adjusted in accordance to the outflow rate. Important differences in the effective protein degradation between FM and the other two protein sources have been found. Applying an outflow rate of 4.4% as found by Hartnell and Satter (1979) the degradation of protein from CSM and SBM was 75% which is in close agreement with in vivo results obtained on re-entrant cannulated cows by Hvelplund and Møller (1980). Fish meal shows a low effective degradation rate.

The influence on different diets' composition or carbohydrate sources on the microbial protein synthesis as well as the degradability of the protein in the rumen is shown in Table 6. It is obvious from the table that the microbial nitrogen production per unit of organic matter apparently digested in the rumen differs between different sources of energy for ruminal fermentation. The digestibility of organic matter in the rumen was highest for the beet rations and lowest for the straw based rations containing structural carbohydrates. The degradability of the urea in the rumen was estimated to 100%, whereas the soya protein on the average was degraded to 75%, and the degradation of the grass and silage protein was 90% and 95% respectively.

The use of formaldehyde-treated protein in rations for dairy cows has been investigated by Madsen (1980) as shown in Table 7. A positive effect on milk yield of protecting a mixture of soya bean meal (SBM) and cotton seed cake (CSC) was

found during the first 5 weeks of lactation but not at later stages in lactation. At the early stage of lactation the protein content in the milk was significantly depressed on protected protein as compared to the period where unprotected protein was fed.

A possibility of the future supply of protein to lactating dairy cows is shown in Fig. 12. The figure illustrates a basic protein supply from roughage and grain during all stages of lactation. Urea can be added at all lactation levels to support the rumen microorganisms with ammonia for microbial protein synthesis if protected protein is added especially at increasing levels of milk yield. Rations for high producing cows probably should be supplied with natural oilcakes of a low degradability for extra supply of amino acids both to rumen microbes and at the intestinal level.

7. CONCLUSION

Experimental results of Danish feeding trials considering the protein:energy relationships in the practical advice of economically optimal amounts of protein per unit of energy expressed as Scandinavian Feed Units have been reported. A large number of experiments during the last decades have concerned the inter-relationships of protein and energy for dairy cows in early lactation. From these experiments production functions determining the maximum milk yields at different protein and energy inputs have been calculated, taking the protein-energy interactions for high levels of milk production into consideration. Economic calculations of the marginal relationships between the price of the protein supplement added per unit of energy and the price of the product (milk or meat) show that the most economical input of protein not in all circumstances coincides with the biological maximum protein level obtained in experiments.

The practical implication of the new understanding of the protein:energy interactions in the rumen obtained during the last 10-15 years indicate that new evaluation systems for protein to ruminants must replace the value of digestible crude protein used in most feeding systems at present. Future protein evaluation systems must take factors as the degradation of protein and the synthesis of microbial protein in the rumen into consideration.

Methods of protecting protein against ruminal degradation will benefit the protein supply of the high producing dairy cows. The requirements of nitrogen for the rumen microbes can partly be met by the inclusion of urea to support the optimal fermentation process in the rumen. The utilization of urea nitrogen for both milk and beef production is favoured by the inclusion of starch or readily digestible cellulose (beet pulp) into the rations.

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Table 1. Maximum protein levels / Sfu at increasing amounts of energy for milk production. (Krohn and Andersen, 1978)

	<u>f.u. for milk production</u>				
	<u>8.o</u>	<u>9.o</u>	<u>10.o</u>	<u>11.o</u>	<u>12.o</u>
g dig. crude protein/p.f.u.	205	196	186	177	167
g dig. crude protein, total per day *)	2060	2184	2280	2367	2424
g dig. crude protein, difference	-	+124	+ 96	+ 87	+ 57

Milk yield and gain

kg milk per cow	26.o	26.5	26.9	27.3	27.5
g daily gain per cow	-540	-420	-300	-180	- 60

*) + 420 g dig. curde protein for maintenance

Table 2. Nitrogen utilization in relation to digestible energy and
NH₃-concentration in rumen fluid.(Møller 1973)

Nitrogen source:	g N utilized/Mcal digested			mg NH ₃ -N/100 ml rumen fluid (ave.)		
	soya	urea	deficient	soya	urea	deficient
<u>Carbohydrate source:</u>						
Corn	2.31	2.32	2.27	18.0	20.4	19.1
Oats-tapioca	2.99	2.41	2.37	21.5	26.1	20.2
Barley	2.79	3.38	2.49	11.4	13.8	4.7
Tapioca	3.17	2.85	2.61	9.3	11.6	8.0
Oats	2.67	2.31	2.31	9.9	14.0	7.6
Mol. beet pulp	3.21	2.95	2.54	11.4	12.3	4.8

Table 3. Synthesis of microbial protein and degradation of feed protein in the forestomachs. (Hvelplund et al., 1976)

	n	Synthesis of microbial protein (g per 100 g DM)	Degradation of feed protein (%)	Equilibrium point of NH_3 accumulation (% protein in DM)
<u>Sheep</u>				
Grass products (artificially dried)	15	6.8	25	27
Barley + concentrates	20	8.7	51	17
Barley + urea	14	12.3	92	13
<u>Cattle</u>				
Mixed rations	55	12.0 ^{*)}	82	15
Beets + urea	5	9.4 ^{*)}	97	10

^{*)} Microbial protein correction for 0.27% endogenous N of DM passing the duodenum and NH_3 -N subtracted from duodenal N.

Table 4. Protein requirements for fattening calves and young bulls.
(Sørensen and Kousgaard, 1976)

Live weight kg	Digestible crude protein, g		Sfu	Microb. protein
	per Sfu	per day	per day	g per day
- 100	155	250	1.6	160
100 - 150	135	400	3.0	300
150 - 200	115	440	3.8	380
200 - 250	100	500	5.0	500
250 - 300	90	500	5.6	560
300 - 350	85	550	6.5	650
350 - 400	80	550	7.0	700
400 - 450	75	550	7.1	710
450 - 500	75	550	7.4	740

Table 5. Daily LW gain and nitrogen utilization of calves receiving soya bean meal or urea. LW: 170-240 kg.

Group	Experiment 1			Experiment 2		
	Soya	Starea	MUB	Molassed beet pulp	Triple nuts	Mol.beet pulp + DUIB
Urea-N, %	0	26.3	28.7	0	42.0	39.3
DM intake, kg/d.	4.2	4.3	4.2	3.5	3.9	3.8
CP in DM, %	13.2	12.8	13.4	8.8	13.4	13.2
N intake, g/d.	88.7	87.4	90.5	48.8	84.2	80.4
N in faeces, g/d.	28.8	26.8	28.5	25.4	30.2	32.4
N in urine, g/d.	23.5	19.5	18.9	9.4	24.8	21.3
Urea-N in urine, g/d.	9.5	8.5	8.0	-	-	-
N retained, g/d.	36.4	41.1	43.1	14.0	29.2	26.8
N retained, % of intake	41.0	47.0	47.7	28.5	34.8	33.4
Daily gain, g	1029	1126	1043	473	864	719
Energy source:	Barley, oats, tapioca, hay (400 g/d.)			Molassed beet pulp, tapioca, hay (400 g/d.)		

Table 6. Organic matter apparently digested in the rumen (OMAP_DR), degradation of supplementary protein, and the microbial N-production per kg OMAP_DR on different diets.
(Hvelplund & Møller, 1980)

Diet	OMAP _D R %	Degradation of protein %	Microbial N-production (g/kg OMAP _D R)
Sugar beets - straw + urea	66.5	100	22.1
Sugar beets - straw + soya	59.7	76	28.2
NH ₃ -treated straw + urea	53.2	100	29.4
NH ₃ -treated straw + soya	52.1	75	29.7
Rye grass	62.9	90	32.5
Silage	52.2	95	30.0

Table 7. Formaldehyde treated protein (SBM + CSC) and urea to high yielding dairy cows (ave. 5 weeks).
(Madsen, 1980)

	Untreated protein	Formaldehyde treated protein	Untreated protein + urea-barley (56%)	Form. treated protein + urea-barley (56%)
Milk, kg/d.	22.8	25.9**	24.0	23.8
FCM, kg/d.	22.8	25.3*	23.6	23.4
Fat, %	4.00	3.86	3.92	3.87
Protein, %	3.28	3.14*	3.21	3.24

Basic ration: Fodder sugar beets, mol. beet pul, straw.

* = $P < 0.05$

** = $P < 0.01$

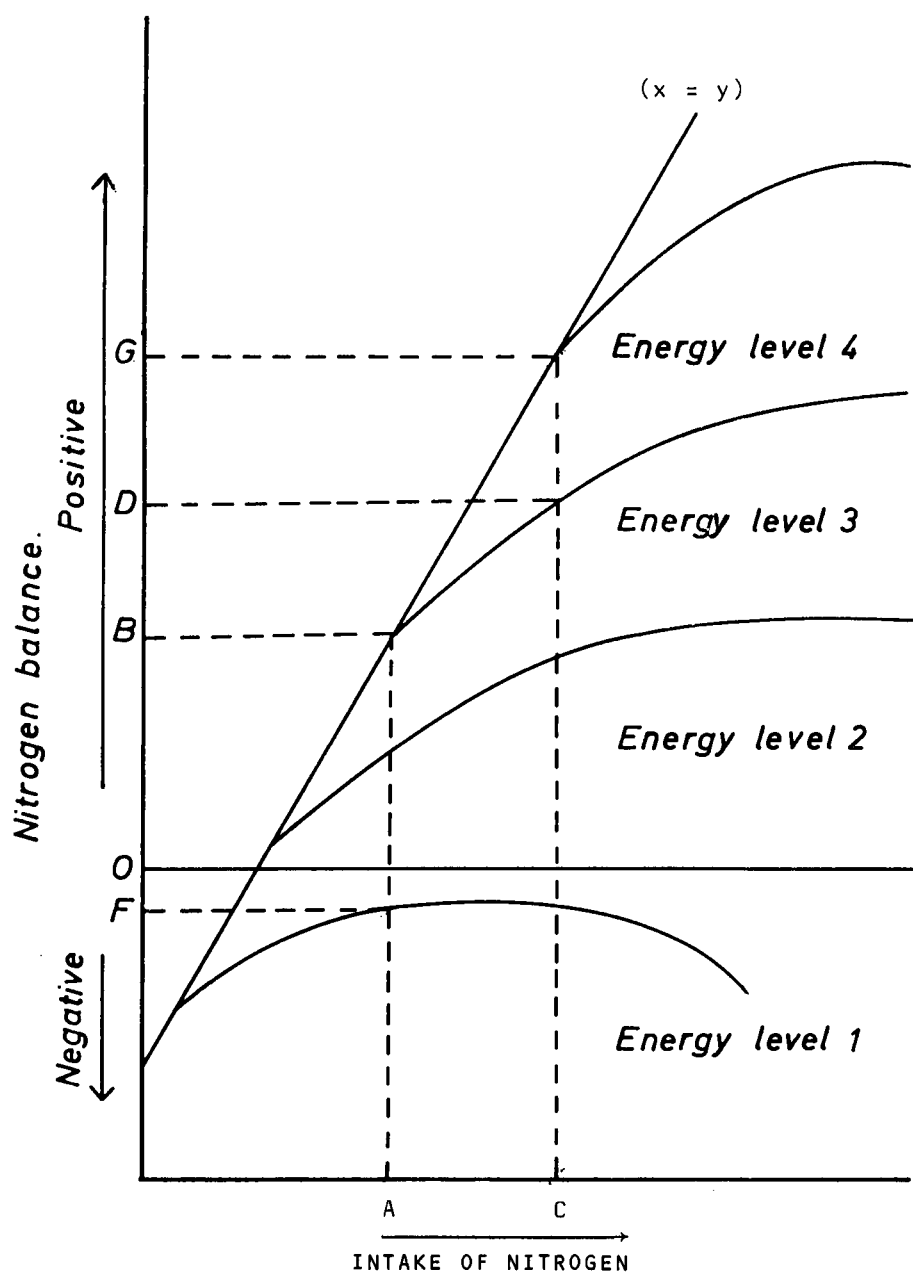


Figure 1. Protein utilization at various energy supplies. (After Balch, 1967)

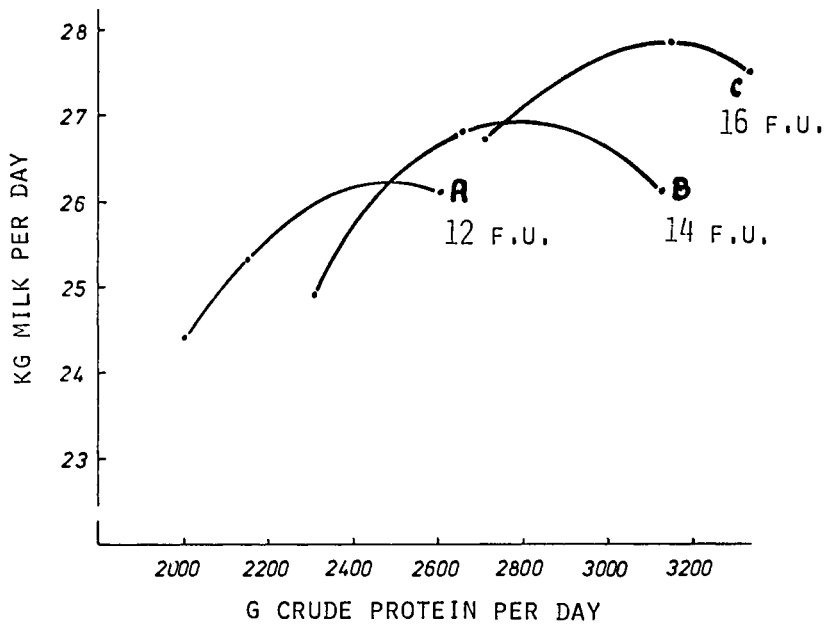
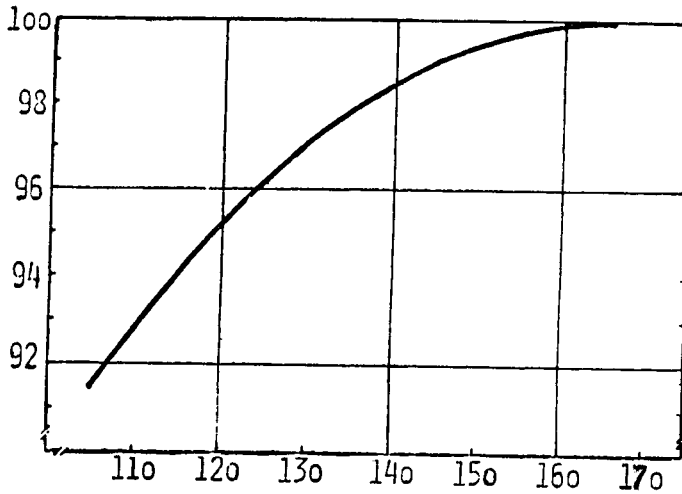


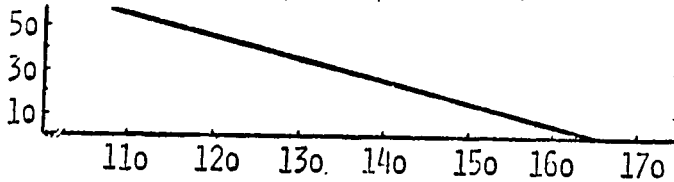
Figure 2. The effect of energy level on relationship between protein intake and milk production. (Krohn and Andersen, 1978)

Relative yield (max.=100)



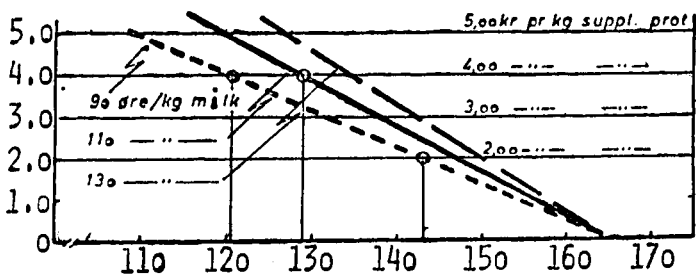
The relationship between g dig. crude protein per P.F.U. and yield

MO in milk per 10 g extra prot. per P.F.U.



Marginal output (MO) in g 4% milk at increasing g prot. per P.F.U.

MI and MC
øre



Marginal income (MI) and marginal cost (MC) for each addition of 10 g prot. at increasing g prot. per P.F.U.

$$\text{g dig. crude protein per kg 4\% milk} = 165 - 10 \times \frac{\text{price protein}}{\text{price milk}}$$

Figure 3. Economical relationships between the optimal input of protein per unit of energy and the price of milk and protein. (Andersen et al., 1973)

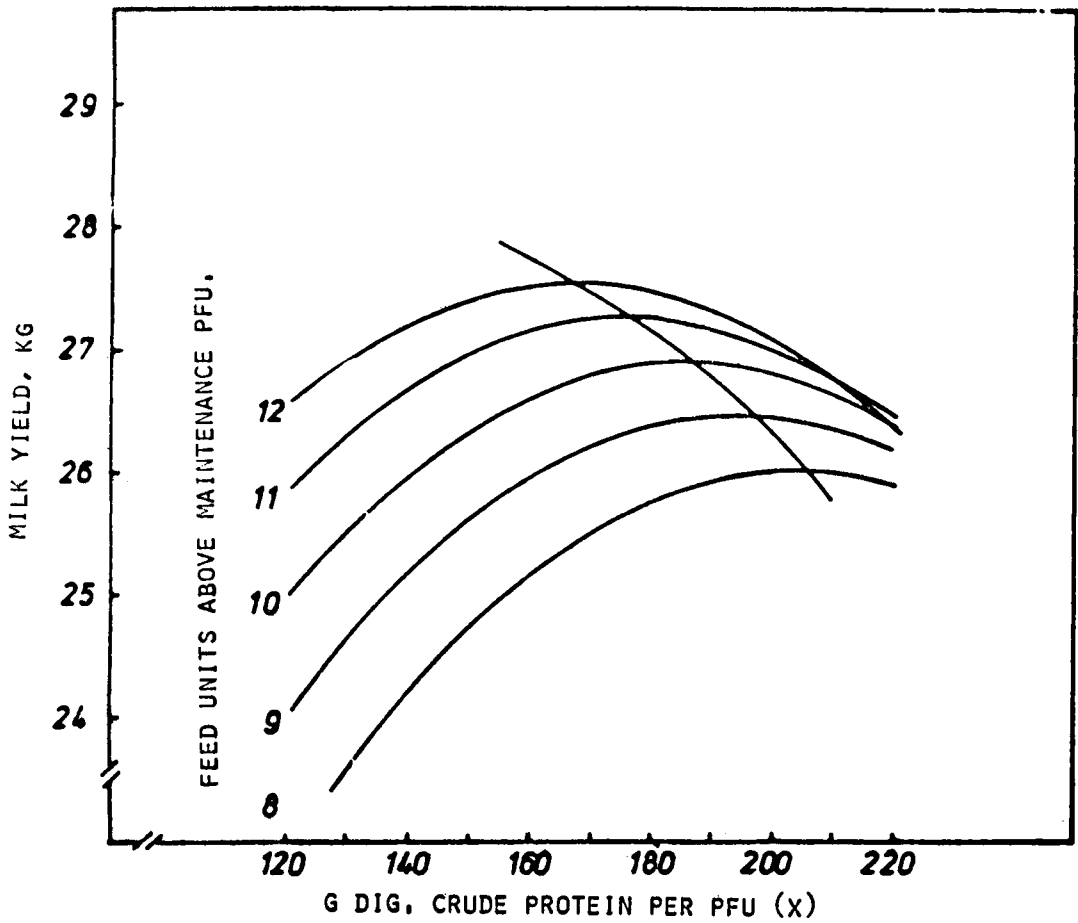


Figure 4. Relations between g dig. crude protein per feed. unit above maintenance and milk production at increasing energy level.

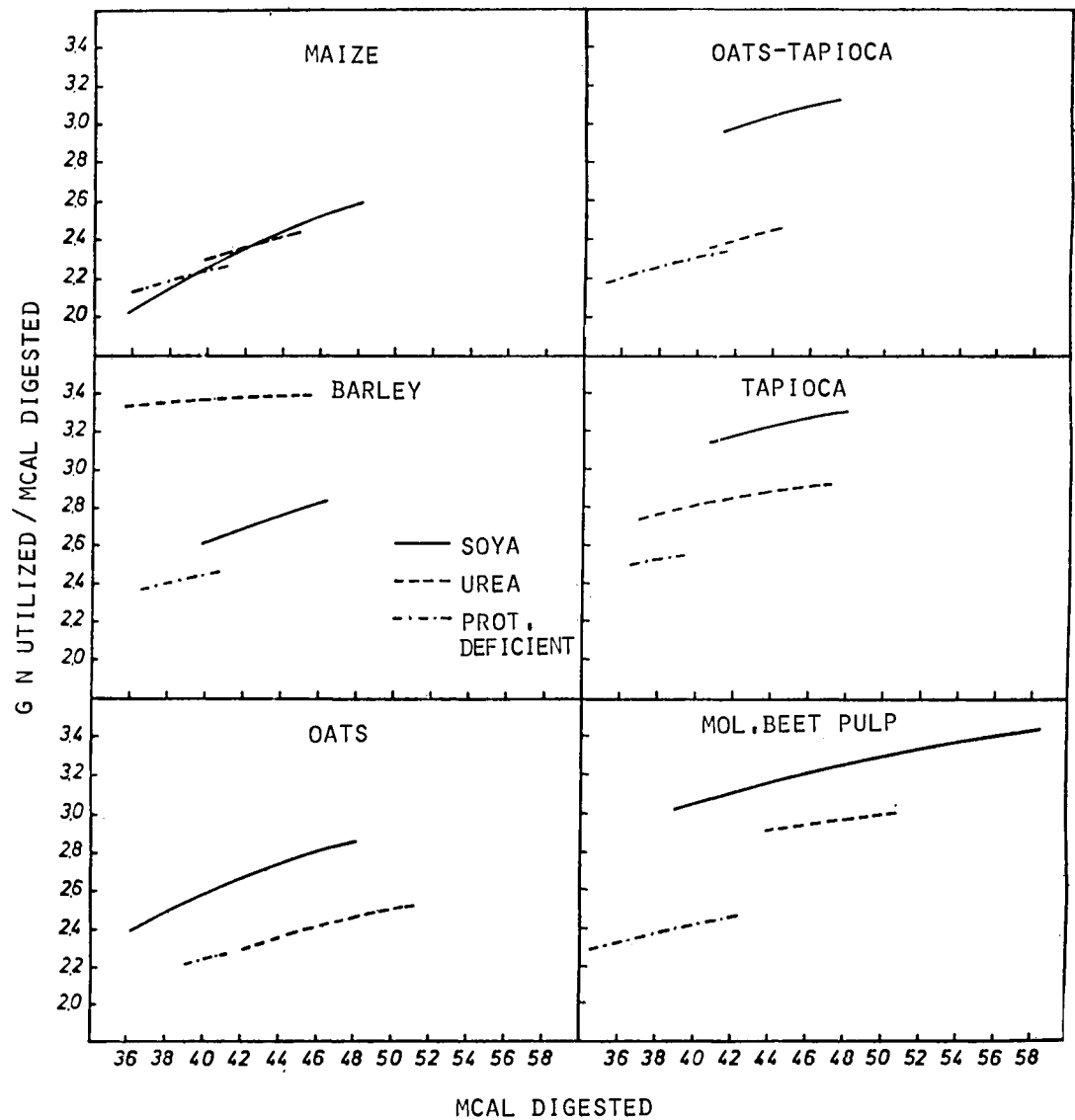


Figure 5. Relationship between nitrogen utilization and digestible energy intake of different starch sources. (Møller, 1973)

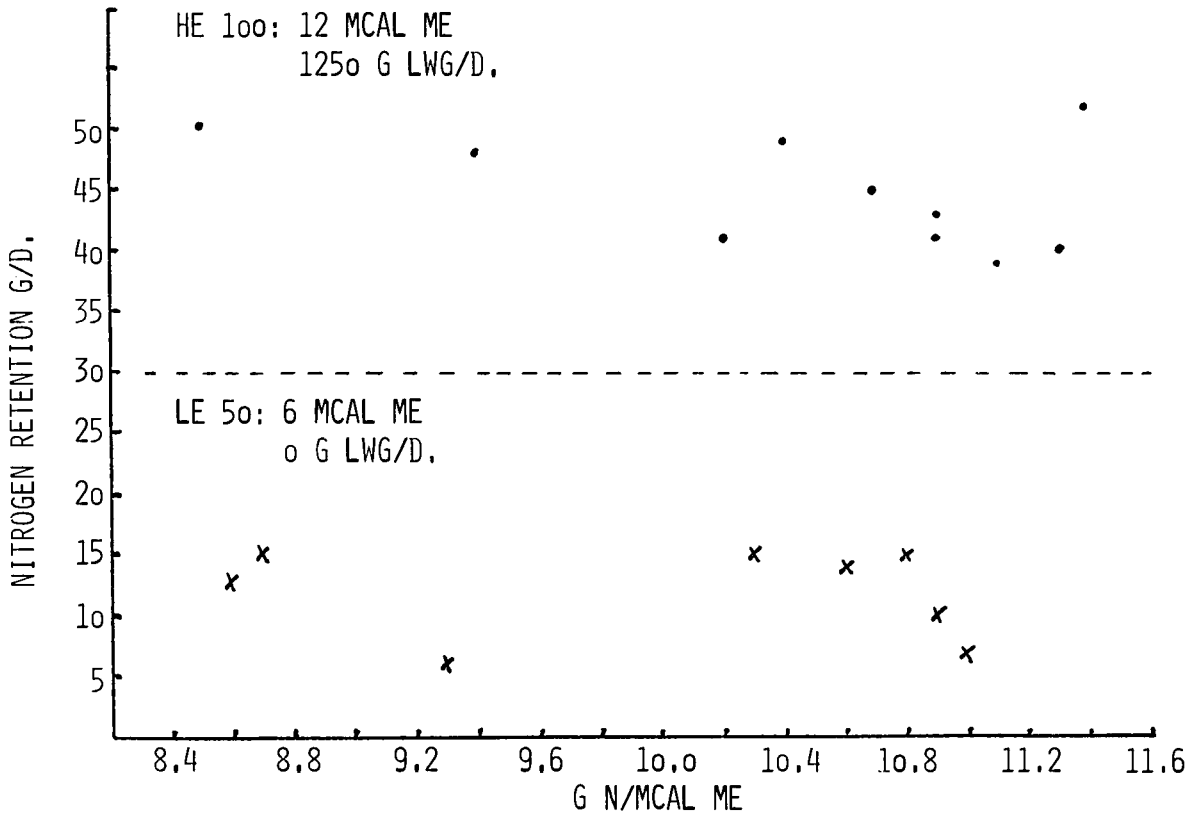


Figure 6. Nitrogen retention of young bulls on high and low energy levels.
(After Thorbek, 1980)

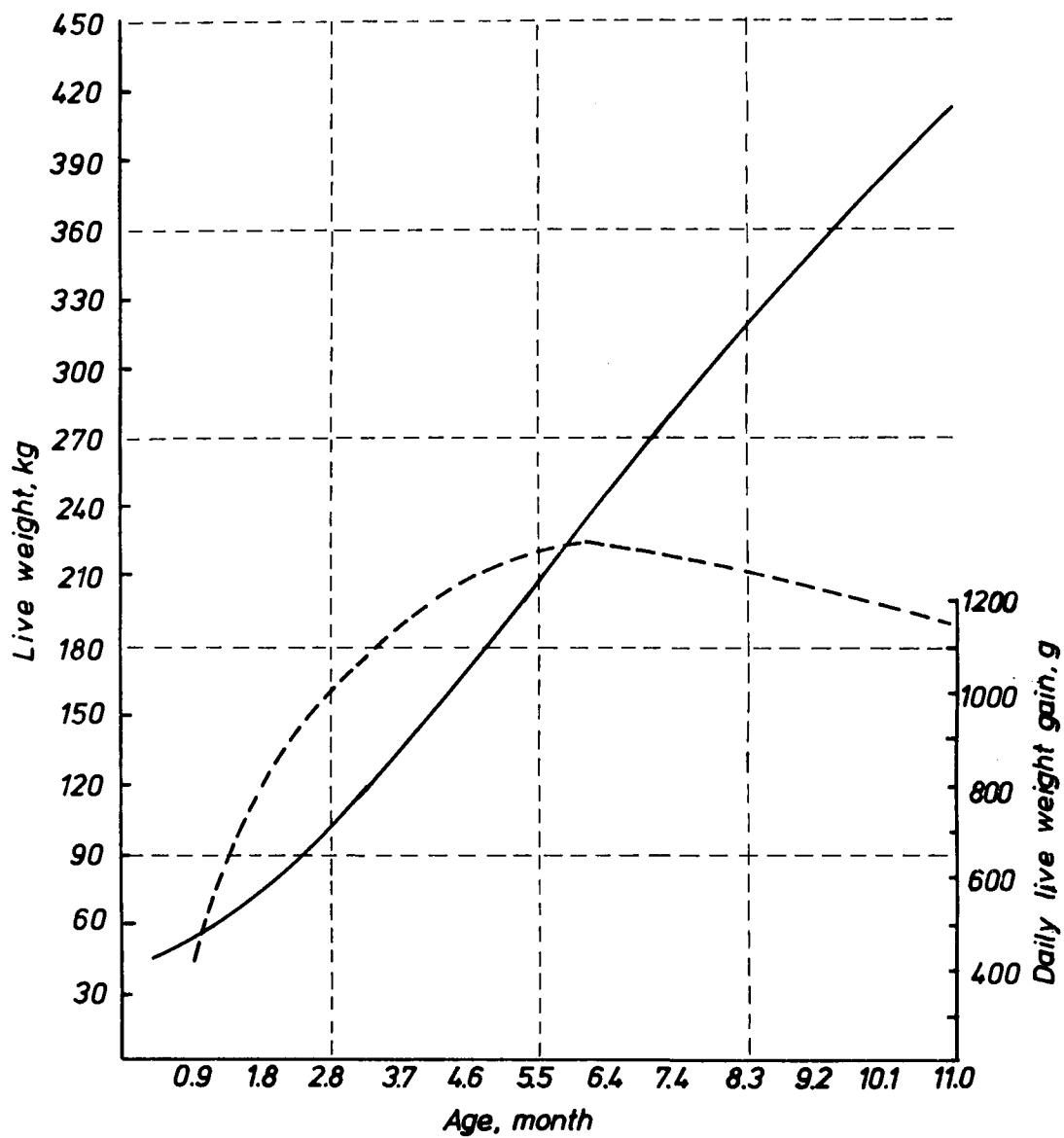
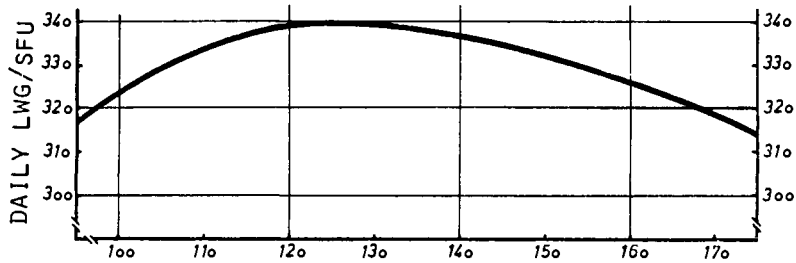
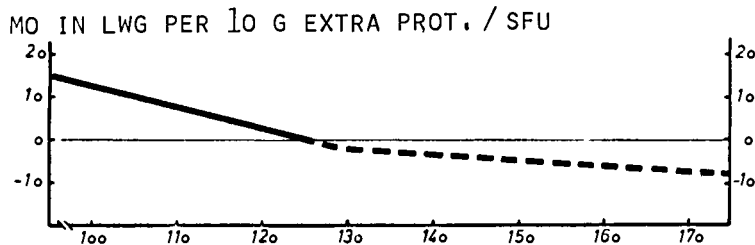


Figure 7. Live weight and daily gain of young bulls (RDM and SDM) for meat production. (Andersen, 1975)

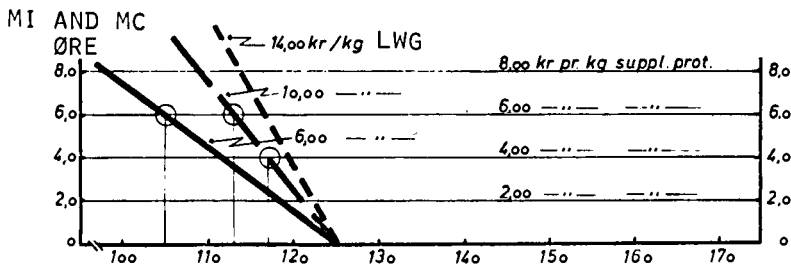
CALVES (48 - 245 kg)



DAILY LWG IN RELATION TO G DIGESTIBLE CRUDE PROTEIN / SFU.



MARGINAL OUTPUT (MO) IN G DAILY LWG AT INCREASING PROTEIN LEVELS PER SFU.



MARGINAL INCOME (MI) AND MARGINAL COST (MC) PER 10 G ADDITIONAL PROTEIN / SFU

$$\text{ECONOMICAL OPTIMAL AMOUNT OF PROTEIN/SFU} = 125 - 20 \times \frac{\text{PRICE SUPPL. PROTEIN}}{\text{PRICE LWG}}$$

Figure 8. Economical relationships between the optimal input of protein per unit of energy and the price of meat and protein.

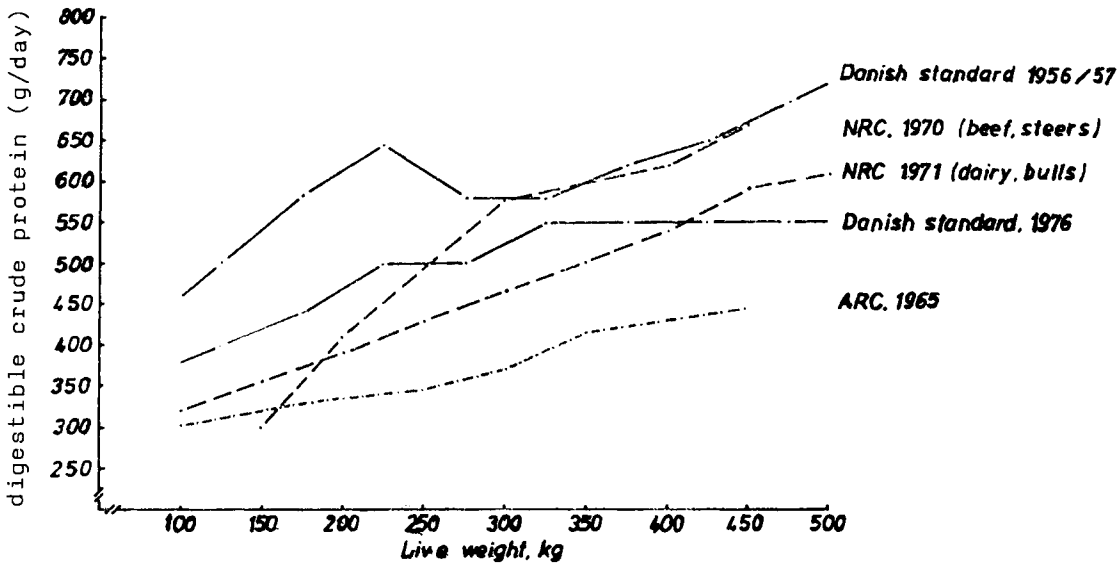


Figure 9. Protein standards for beef production.

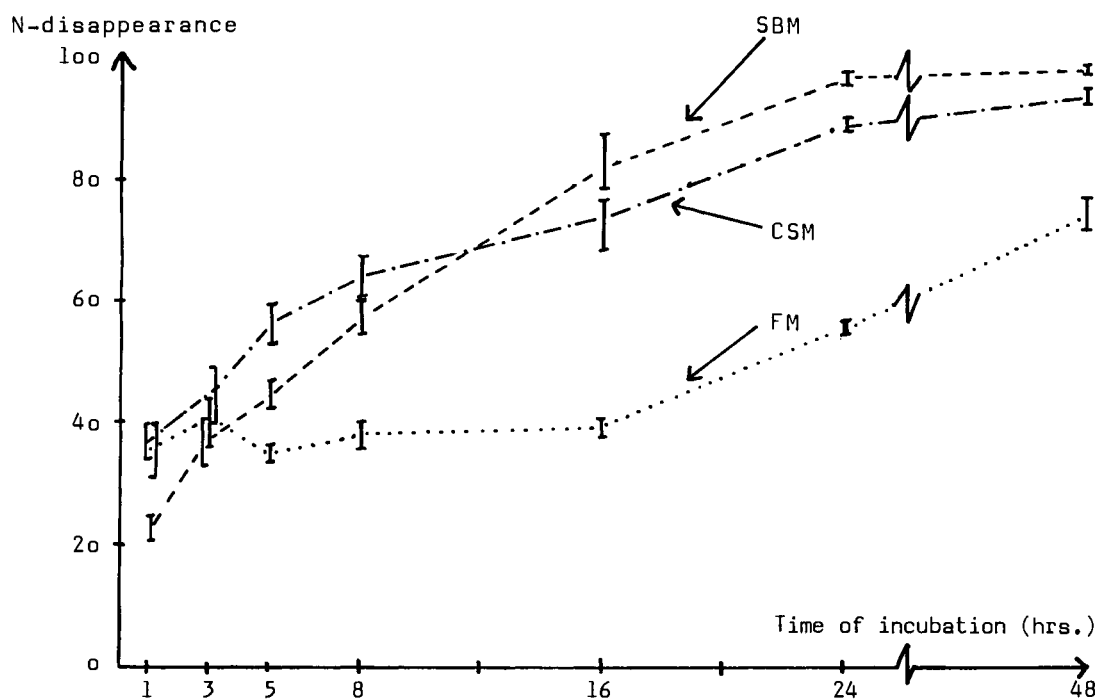


Figure 10. The N-disappearance from nylon bags as a function of incubation hours for soya bean meal (SBM), cotton seed meal (CSM) and fish meal (FM).

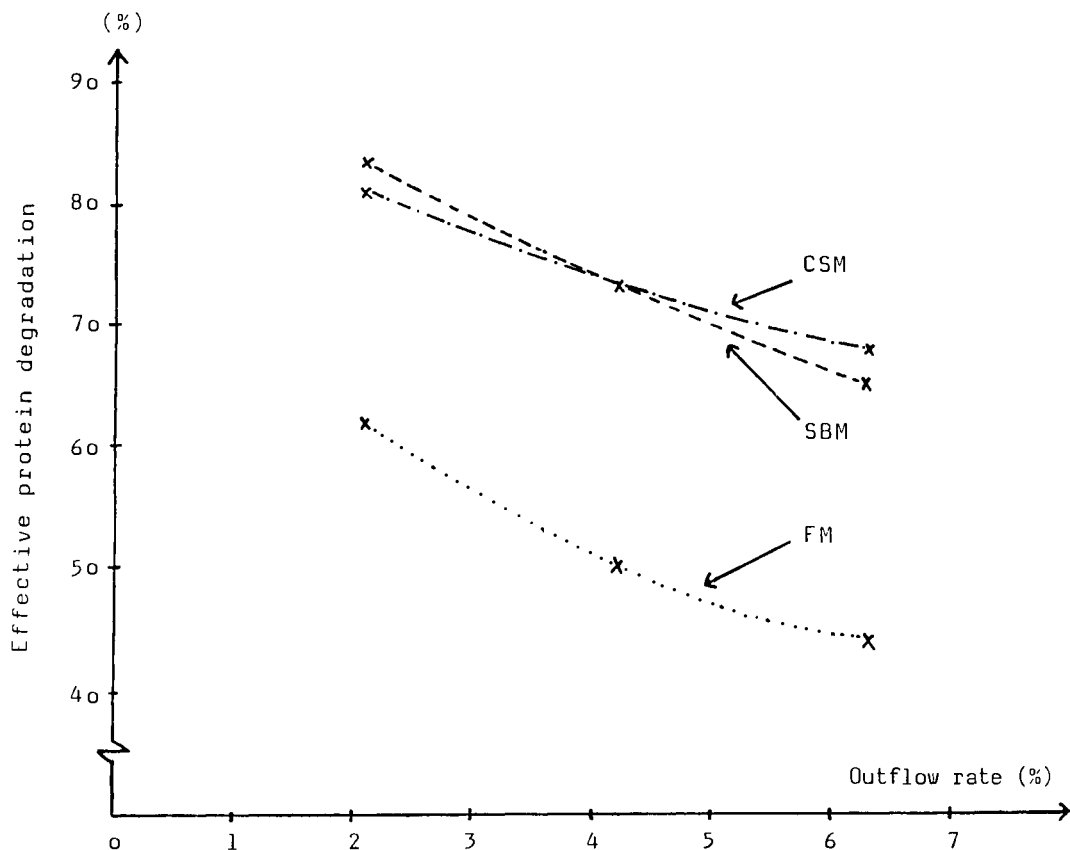


Figure 11. The effective protein degradation in the rumen as a function of outflow rate from the rumen for soyabean meal (SBM), cotton seed meal (CSM) and fish meal (FM).

$$\text{Effective prot.deg.} = \sum_{i=0}^n (N\text{-dis}(t_{i+1}) + N\text{-dis}(t_i)) \times f(t_i, t_{i+1})$$

$$f = \text{proportion remaining in rumen} = \frac{e^{-kt_i} + e^{-kt_{i+1}}}{2}$$

k = rate constant of proportion leaving rumen per hour.

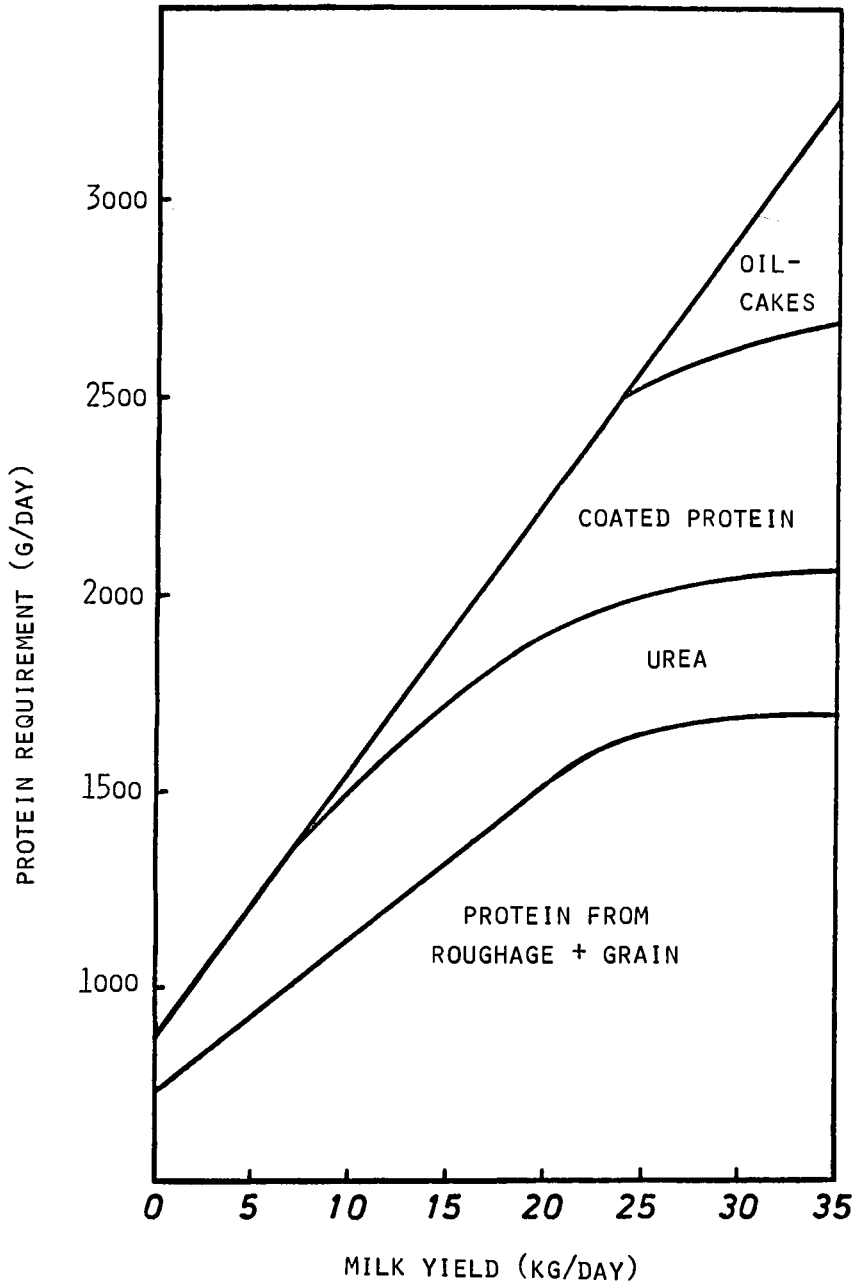


FIGURE 12. FUTURE SUPPLY OF PROTEIN TO LACTATING DAIRY COWS.